Aerospace Technology Enterprise

Annual Progress Report 2002

the role of the aerospace technology enterprise pioneers and validates high-payoff technologies

- to improve the quality of life;
- to enable exploration and discovery;
- to extend the benefits of our innovation throughout our society.

the enterprise accomplishes this role through advanced research in aviation systems, space launch and in-space technologies, innovative processes and technology and the transfer of technology to the commercial sector.

our success is measured by the extent to which our results improve the quality of life and enable exploration and scientific knowledge.

the year 2003 marks the centennial of powered flight. to celebrate this—the office of aerospace technology has taken on a new look for its annual report—remembering our past and focused on the future of flight.

A REPLICA OF THE WRIGHT FLYER IN THE NASA LANGLEY FULL-SCALE WIND TUNNEL AT OLD DOMINION UNIVERSITY.

Message to **the Reader**

In 1903, the Wright brothers realized the ancient dream of human flight—a century later NASA is pioneering the future of flight today.

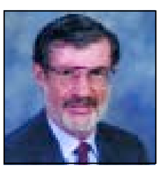
As we commemorate the 100th Anniversary of Flight, the United States is still boldly pioneering the air and space frontier. During this remarkable century, air travel has changed our lives in many ways. Journeys that once took weeks or months of dangerous travel now take a few hours. In space, we landed humans to explore the Moon and continue to send our robotic emissaries to roam the distant planets of our solar system.

For the past 45 years NASA's aviation and space transportation investments have transformed our society by providing safe, affordable transportation, creating global economic wealth, providing unrivaled national security, unlocking vast secrets of science and the cosmos, and providing a remarkable quality of life.

Over the past year, NASA's Aerospace Technology Enterprise has forged ahead with bold new technologies in both aviation and space access. These cutting-edge technologies will make air travel safer and more convenient while improving environmental compatibility. Our efforts support NASA's mission of understanding and protecting our home planet, exploring the universe and searching for life, and inspiring future generations of explorers.

The accomplishments in this report represent only a part of the total work achieved by the Aerospace Technology Enterprise. These accomplishments are not all final achievements—many represent a milestone along a technology path. This path will lead to a new era in aviation and space transportation, improving our quality of life and benefiting the Nation and the world.

Enterprise Executive Board



Dr. Jeremiah F. Creedon
AA for Aerospace Technology
NASA Headquarters
(202) 358-4600
jeremiah.f.creedon@nasa.gov

Mr. Delma Freeman
Center Director
Langley Research Center
(757) 864-1000
D.C.Freeman@larc.nasa.gov

Mr. Scott Hubbard
Center Director
Ames Research Center
(650) 640-5111
G.Scott.Hubbard@nasa.gov

Mr. Kevin L. Petersen
Center Director
Dryden Flight Research Center
(661) 258-3101
kevin.petersen@mail.dfrc.nasa.gov

Mr. Donald J. Campbell
Center Director
John H. Glenn Research
(216) 433-2929
Donald.J.Campbell@grc.nasa.gov

Mr. Arthur G. Stephenson
Center Director
Marshall Space Flight Center
(256) 544-1910
Arthur.G.Stephenson@msfc.nasa.gov

Table of **Contents**

NASA has a new vision and mission with a single set of agency goals and objectives that encompass the efforts of all six NASA enterprises. Our success is measured by the extent to which our results improve the quality of life and enable exploration and the growth of scientific knowledge.

In February 2003, NASA published a new Strategic Plan that emphasizes a "One NASA" approach and a single set of 10 Agency Goals. The 18 organizing categories through which the Agency Goals are accomplished are called "Themes."

The Aerospace Technology Enterprise is responsible for 4 of those 18:

- Aeronautics Technology
- Space Launch Initiative
- Mission and Science Measurement Technology
- Innovative Technology Transfer Partnerships

The Aerospace Technology Enterprise contributes to the NASA Vision and Mission through development of pioneering tools, processes and technologies. These in turn will enable future air and space transportation systems, access to space, and new science missions.

The details supporting this new structure are shown graphically on the following pages.

For a complete look at the Agency Vision, Mission and Goals, please refer to the 2003 NASA Strategic Plan available online at: *http://www.nasa.gov*

Aerospace Technology Enterprise Themes

Beginning in FY 2003 these themes and their "Theme Objectives" have become the guides for our research programs. Following is a brief description of the work performed under each Theme.

Aeronautics Technology Theme. The Enterprise has a unique role in NASA as sole administrator of the Agency's aeronautics investments. NASA Aeronautics Technology helps create technology for a safer, more secure, more environmentally friendly, and more efficient air transportation system. It also enables improved performance of military aircraft and it finds new uses in science and commercial missions. The enterprise supports our nation's security through its partnerships with the DOD and FAA.

Space Launch Initiative Theme. The Enterprise has been tasked to ensure safe, affordable, and reliable access to space. New space transportation capabilities are needed to ensure that America continues its leadership in space. Collaboration with DOD on critical access to space and hypersonic technologies helps create a more secure world in support of future military and civil aerospace missions. Special emphasis is given to NASA-unique needs including crew escape and survival systems, which will be developed by the private sector with government funding.

Mission and Science Measurement Technologies Theme. The Enterprise also is responsible for developing crosscutting technology for a variety of aviation and space applications, such as communications, power and propulsion systems, microdevices and instruments, information technology, nanotechnology, and biotechnology. These technology advances will have the potential to open a new era in aviation and allow space missions to expand our knowledge of Earth and the universe. Once developed, these technologies often find their way into commercial applications.

Innovative Technology Transfer Partnerships Theme. The Enterprise works to form partnerships with industry and academia in order to develop new technology that supports enterprise programs. NASA also will commercialize and transfer technology to U.S. industry and enhance its technology and commercial objectives through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

Reporting on Enterprise Accomplishments

Our Goals and Objectives reflect the real national needs that are aligned with our Enterprise mission. To "stretch" beyond what is possible today, the Enterprise continually pursues and evaluates new, innovative and evolutionary technologies. To be successful, revolutionary technologies also must be developed and integrated into the new aerospace systems and vehicles of the future.

This Annual Report highlights our Enterprise accomplishments for FY 2002. Many of these accomplishments represent major steps or milestones along a technology development path. While all are not yet in final form, they all demonstrate noteworthy progress achieved toward our ultimate goals and objectives.

Our FY 2002 accomplishments have been organized in response to the new NASA 2003 Strategic Plan and the new Agency Goals and Objectives supported by the Aerospace Technology Enterprise. The chart on the following page traces the linkage from our previous Enterprise Goals and Objectives to the new Agency Goals and Objectives. In most cases, there is a direct correlation between the 2002 and 2003 goals and objectives, though in some cases assignments have changed and the new relationship is less clear.

For more information and insight on our 2002 accomplishments, please visit our website and browse through the online version of this report. Links to related information can be found on the website of our research centers. Begin your search at: *http://www.aerospace.nasa.gov*

NASA mission and goals.

2002 Enterprise Goals and Objectives

Goal One: Revolutionize Aviation
1. Increase Safety
2. Reduce Emissions
3. Reduce Noise
4. Increase Capacity
5. Increase Mobility

Goal Two: Advance Space Transportation
6. Mission Safety
7. Mission Affordability
8. Mission Reach

Goal Three: Pioneer Technology Innovation
9. Engineering Innovation
10. Technology Innovation

Goal Four: Commercialize Technology

Aerospace Technology Enterprise
2002 Goals and Objectives Structure

This chart maps Aerospace Technology Enterprise objectives from the 2000 Enterprise Strategic Plan into the Agency's 2003 NASA Strategic Plan structure. No lines or multiple links indicate, respectively, the creation of new objectives at the Agency level, or organizational changes within the original objectives.

2003 Agency Goals and Objectives

2. Enable a safer more secure efficient and environmentally friendly air transportation system.
- 2.1 Protect Air Travelers and the Public
- 2.2 Protect the Environment
- 2.3 Increase Mobility

3. Create a more secure world and improve the quality of life.
- 3.1 Support National Security
- 3.2 Support National Security
- 3.3 Extending Benefits to Society

7. Engage the public in shaping and sharing the experience of exploration and discovery.
- 7.3 Increase Public Awareness and Understanding

8. Ensure the provisions of space access and improve it.
- 8.1 Assured ISS Access
- 8.2 Mission Safety and Affordability

10. Enable revolutionary capabilities through new technology.
- 10.1 Mission Risk Analysis
- 10.2 Science Driven Architecture and Technology
- 10.3 Create Knowledge from Scientific Data
- 10.5 Explore Revolutionary Aerospace Concepts
- 10.6 Tapping U.S. Non-Aerospace Capabilities

Restructured into Enterprise Support of
Agency 2003 Strategic Plan Goals and Objectives

2003 Agency **Goals and Objectives**

Aeronautics Technology Theme

Agency Goal 2

Enable a safer, more secure, efficient, and environmentally friendly air transportation system.

Objective 2.1
Protect Air Travelers and the Public

Decrease the aircraft fatal accident rate and the vulnerability of the air transportation system to threats and mitigate the consequences of accidents and hostile acts.

Objective 2.2
Protect the Environment

Protect local and global environmental quality by reducing aircraft noise and emissions.

Objective 2.3
Increase Mobility

Enable more people and goods to travel faster and farther, with fewer delays.

Agency Goal 3

Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.

Objective 3.2
Support National Security (Aeronautics)

Enhance the Nation's security through aeronautical partnerships with DOD and other government agencies.

Agency Goal 10

Enable revolutionary capabilities through new technology.

Objective 10.5
Explore Revolutionary Aerospace Concepts

Create novel aerospace concepts to support Earth and space science missions.

Space Launch Initiative Theme

Agency Goal 8

Ensure the provision of space access and improve it by increasing safety, reliability, and affordability.

Objective 8.1
Assured ISS Access

Assure safe, affordable, and reliable U.S.-based crew access and return from the International Space Station.

Objective 8.2
Mission Safety and Affordability

Improve the safety, affordability, and reliability of future space transportation systems.

Agency Goal 3

Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.

Objective 3.1
Support National Security (Space Access)

Enhance the Nation's security by developing and demonstrating critical access-to-space technologies that benefit NASA, DOD, and other Government agencies.

Agency Goal 9

Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery.

Objective 9.5
Support for Space Exploration

Develop innovative approaches and concepts to inform future decisions concerning systems, infrastructures, and missions for the human and robotic exploration of space.

Mission and Science Measurement Technology Theme

Agency Goal 10
Enable revolutionary capabilities through new technology.

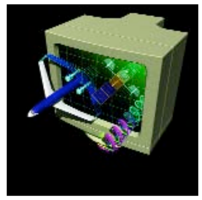
Objective 10.1
Mission Risk Analysis
Improve the capability to accurately assess and manage risk in the synthesis of complex systems.

Objective 10.2
Science Driven Architecture and Technology
Create system concepts and demonstrate technologies that enable new scientific measurements.

Objective 10.3
Create Knowledge from Scientific Data
Develop breakthrough information and communication systems to increase our understanding of scientific data and phenomena.

Agency Goal 9
Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery.

Objective 9.2
Support for Human Space Flight
Develop knowledge and technologies to make life-support systems self-sufficient and improve human performance in space.



Innovative Technology Transfer Partnerships Theme

Agency Goal 3
Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.

Objective 3.3
Extending Benefits to Society
Improve the Nation's economic strength and quality of life by facilitating the innovative use of NASA technology.

Agency Goal 10
Enable revolutionary capabilities through new technology.

Objective 10.6
Tapping U.S. Non-Aerospace Capabilities
Enhance NASA's Mission by expanding partnerships between NASA Enterprises and nonaerospace U.S. industrial firms and by leveraging the venture capital community for innovative technology development.

		Theme 1 Aeronautics Technology	Theme 2 Space Launch Initiative	Theme 3 Mission & Science Measurement Technology	Theme 4 Innovative Technology Transfer Partnerships
MISSION I	2 Enable a safer, more secure, efficient, and environmentally friendly air transportation system.	□			
MISSION I	3 Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia	□	□		□
MISSION III	6 Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.	○	○	○	○
MISSION III	7 Engage the public in shaping and sharing the experience of exploration and discovery.	□	○	○	○
Enabling Goals	8 Ensure the provision of space access and improve it by increasing safety, reliability, and affordability.		□		
Enabling Goals	9 Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery.		○	○	
Enabling Goals	10 Enable revolutionary capabilities through new technology.	□		□	□

Relationship of Agency Goals to the Themes under the responsibility of the Aerospace Technology Enterprise. □ Primary ○ Support

Artist concept of future aircraft with revolutionary capabilities. A new airspace system will allow greater options for air travel and greater accessibility and affordability to the public.

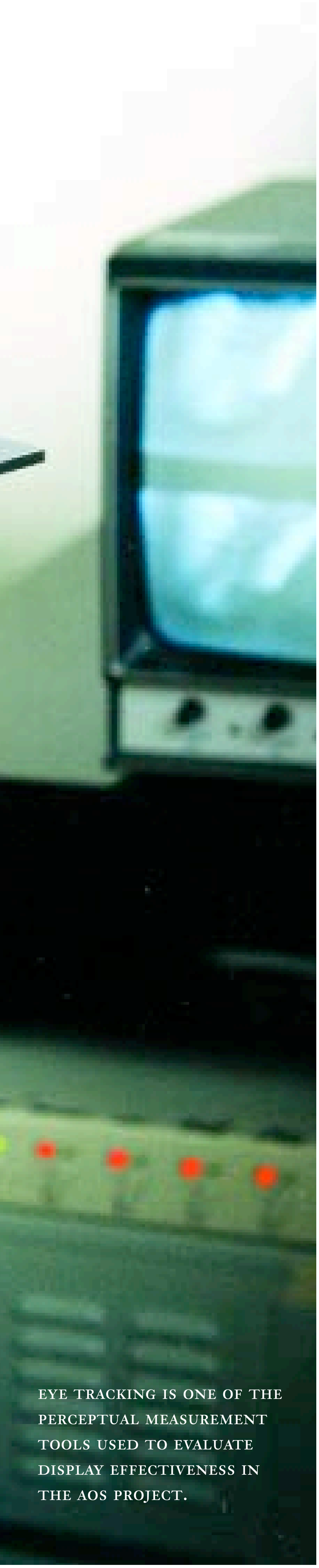
Aeronautics Technology Theme

Expanding our aviation system to meet demands for future growth will mean providing a more distributed, flexible, and adaptable network of airways. This growth must take place within the physical and environmental constraints of today's system, while also meeting the evolving needs of air travel. The system of the future will continue to be international in scope, requiring close coordination across a global network.

Advanced vehicles will operate in this new infrastructure with better performance and new capabilities. Advanced information and sensor technologies will make air travel safer and more efficient. Air transportation will be easily accessible from urban, suburban, and rural communities. Airplanes will be cleaner, quieter, and faster.

NASA aims to revolutionize aviation by delivering the long-term, high-payoff aerospace technologies, materials, operations, and research needed to enable development of new vehicles and system capabilities, including concepts to support Earth and Space Science missions.

The following pages report key accomplishments the Aerospace Technology Enterprise achieved toward realizing this goal. Expanded write-ups, images, and videos can be found on the supporting website at: *http://www.aerospace.nasa.gov*



EYE TRACKING IS ONE OF THE PERCEPTUAL MEASUREMENT TOOLS USED TO EVALUATE DISPLAY EFFECTIVENESS IN THE AOS PROJECT.

Aeronautics Technology Theme. **Agency Goal 2**

Objective 2.1 **Protect Air Travelers and the Public**

Decrease the aircraft fatal accident rate and the vulnerability of the air transportation system to threats and mitigate the consequences of accidents and hostile acts.

In cooperation with the Federal Aviation Administration (FAA) and the aviation industry, NASA research and technology efforts will continue to address accidents and incidents involving hazardous weather, controlled flight into terrain, human-performance related causal factors, mechanical or software malfunctions and the development and integration of information technologies needed to build a safer airspace system and provide information for the assessment of situations and trends that indicate unsafe conditions before they lead to accidents.

NASA has examined the historical aviation accident trends and determined high payoff technologies that will improve the safety of the National Airspace System.

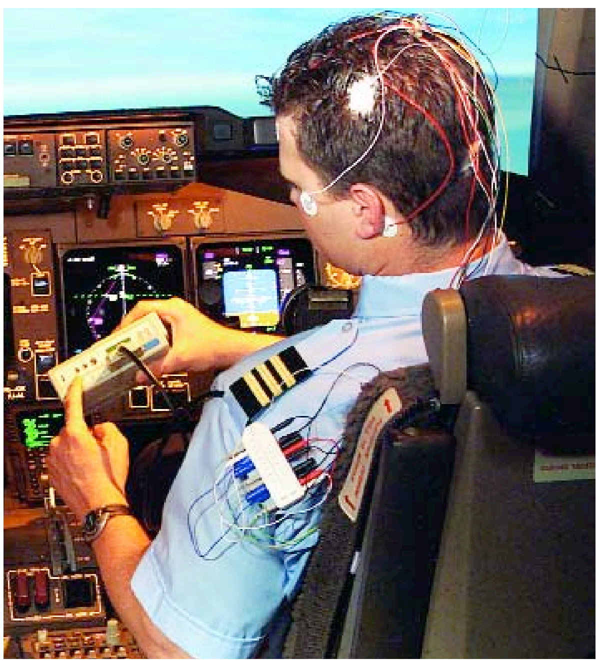
After the events of September 11, 2001, technology research in the area of aviation security was added to NASA's role. The research program is under formulation and plans to leverage relevant work from existing related research. As such the following accomplishments address aviation safety. Accomplishment reports on aviation security will be provided beginning next year.

Motivated by the awareness that people operating within the air transportation system are ultimately responsible for air travel safety and reliability, the NASA Airspace Operations Systems Project is developing human-centered design concepts and automation philosophies to improve the efficiency and effectiveness of aircraft pilots and air traffic controllers. During the past year, numerous studies have been conducted in support of this objective including eye-movement tracking, image processing, visual system modeling, and auditory system modeling.

The importance of these "psychophysical" studies is demonstrated through transfer of the study findings to applications in aviation, medicine, and education. The following sections provide FY 2002 highlights and accomplishments in this area.

Resting for Peak Performance

Flight crew fatigue, caused by extended flight/duty times and crossing multiple time zones, has been repeatedly identified as a performance and safety issue in aviation operations. To help improve the probability that rested and alert crews are in the cockpit, a software-based scheduling tool was developed to help predict flight crew performance and changes in alertness based on sleep and circadian patterns. The scheduling tool uses a biomathematical model of alertness developed by a team at Harvard University. It has been modified for use in flight operations based on detailed cognitive, subjective, environmental, and flight performance data collected during long-haul commercial flights. The tool helps users recommend pilot work and rest schedules to reduce in-flight fatigue during commercial flight operations.



Pilot brainwave activity is monitored in the Crew Vehicle System Research Facility Boeing 747-400 simulator in a study to determine fatigue, sleep loss, and circadian rhythm disruption during long- and extra-long-haul flights.

Working with Human Nature

As our reliance on machines increases—the potential for problems grows. Poorly designed user interfaces and manuals have resulted in training errors, in-flight incidents, and worst of all, accidents. To improve the performance and effectiveness of human beings in these vital situations, the Airspace Operations Systems Project is investigating how pilots and air traffic controllers actually interact with highly complex automated control systems. Results of these investigations have been used to produce formal methods and procedures for the verification and design of human-automation interaction.

These methods help to improve pilot performance in terms of accuracy and reliability of actions in high-pressure situations. The new design tools have already been successfully applied to the user interfaces for several autopilot and flight control programs.

Life Saving Training

Ice—on the ground—or in the air—has been a serious, dangerous problem for pilots and their passengers since the start of powered flight. To get the upper hand in the battle with aircraft icing, researchers at the NASA Glenn Research Center developed a new computer-based training (CBT) aid for professional and private pilots, and pilots-in-training, that provides tools and information to help avoid, detect, and minimize ice exposure. Effects of icing on aircraft performance, control upsets (wing and tail stalls), and recovery procedures are explained.

This self-paced CBT improves on an existing instructor-led *In-Flight Icing Training* CBT with new exercises for pilots and pilots in training. Images from the NASA Icing Research Aircraft and Icing Research Tunnel, testimonials, animation, case studies and interactive demonstrators supplement the training.

The FAA, Air Line Pilots Association, and the University of Oregon worked with NASA to develop this training. NASA plans to continue development of electronic-based training on icing in the future. More than 3,500 copies have been distributed to airlines, training and academic institutions, manufacturers, the FAA, and Transport Canada. This CBT also has been distributed internationally.

A Real Ice-Breaker

To help improve aircraft performance during icy weather, computational icing simulation is making the transition from a research tool to more commonplace use in design and certification.

The LEWICE project is serving as an introduction to the concepts of software management and is intended to serve as a pilot project for future icing simulation developments.

The LEWICE Version 2.2 Ice Accretion Computational Tool has been enhanced in FY 2002 by adding thermal ice protection subroutines for modeling hot air and electro-thermal anti/de-icing systems. This systems analysis capability has advanced the state of the art to allow aircraft manufacturers to determine—prior to testing—whether ice protection system designs will prevent ice formation or remove existing ice accumulations. This software will assist original equipment manufacturers in developing better designs to cope with icing effects and certification of these designs.

Glace Ice formation commonly referred to as "Lobster Tail" by scientists and engineers, under certain conditions forms on the leading edge of an aircraft tail section. Studies of icing conditions and resulting build up are conducted in the icing research tunnel at the NASA Glenn Research Center.

Weather Awareness—Or Not

Operating within the Aviation Safety Program's Weather Accident Prevention Project—and a year early—a team from FAA, industry, academia, and NASA developed and integrated a series of key technologies needed for improved cockpit weather information systems for both commercial and general aviation (GA) aircraft.

Improved in-cockpit graphical systems are expected to provide a 50 percent reduction in aircraft accidents due to a lack of weather situational awareness. Weather effects on GA pilot decisions were studied on the NASA B200 King Air research aircraft with a tethered display from Honeywell. Digital datalink technologies also were demonstrated on the Ohio University King Air and the NASA Learjet aircraft.

Technologies from this project will improve operational efficiency by allowing strategic avoidance of weather, a major benefit given that weather causes most air traffic delays. Data from these flights also contributed to defining the FAA Minimum Aviation System Performance Standards for Flight Information Services. These efforts helped make new commercial subscription-based cockpit weather services possible—bringing graphical information to the GA cockpit for the first time.

Getting a New View of Lightning

Lightning has always been a major safety problem for aircraft. While the instantaneous voltage and heat effects are readily observed—these are not the only problems.

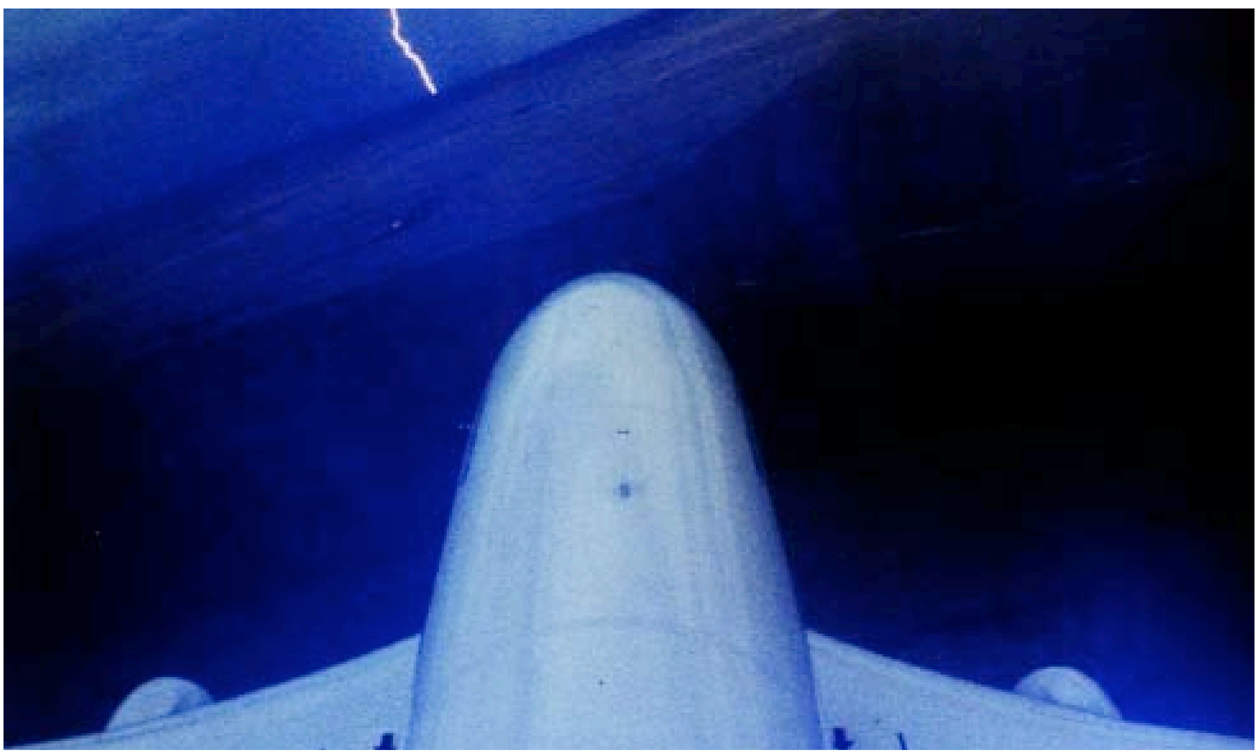
To assess the impact of lightning and other electromagnetic interference on aircraft structure and avionics systems, NASA has developed simulations using new physics-based computational tools developed at the NASA Langley Research Center to enable a more accurate, safe, and cost-effective way to study lightning.

AWIN-WIN for Pilots and Passengers

In partnership with the FAA, industry, and academia, NASA demonstrated technologies to give pilots more up-to-the-minute weather forecasts to help safely guide aircraft around dangerous weather.

The international Aviation Weather Information Network (AWIN) provides critical data and information on potentially hazardous in-flight weather conditions. Prior to AWIN, pilots had to rely on preflight weather briefings and occasional in-flight pilot reports. Real-time up-to-the-minute forecasts were unavailable in the cockpit.

In FY 2001, a national AWIN capability for the display of radar weather information for transport and



Langley's 737 flying laboratory flew over 130 missions into extreme weather situations, learning how to hunt invisible wind shear elements two to three miles ahead of the aircraft. This research contributed to better cockpit technologies for detecting wind shear.

GA aircraft was developed and demonstrated under a NASA Cooperative Research Agreement (CRA).

A communication infrastructure for in-flight distribution of weather information was also demonstrated under a NASA CRA. These technologies enabled development of the first generation of AWIN equipment, leading to release of more than 10 products. In FY 2002, NASA demonstrated the capability to integrate aircraft weather communications infrastructure and did it in an international environment.

Now pilots see current weather radar information—and receive and send turbulence reports and storm forecasts. As a result—pilots now can plan course changes more effectively to avoid hazardous weather.

How to Skip Over Bumpy Air

During FY 2002, collaborations between industry and NASA reached key goals as much as a year ahead of schedule—supporting early completion of milestones for graphical weather display technologies. Flight demonstrations included:

- In-Service Evaluations of the Honeywell Weather Information Network transport system by United Airlines. Benefits include turbulence mitigation.

- First use of true Internet Protocol to a FAR 121 flight deck via sky phone technology. Used on commercial aircraft for passenger telephony, a dial-up modem was used to provide low data rate digital transfer of graphical weather information.

- The Rockwell Enhanced Weather Radar system demonstrated uplinked Next Generation Radar (NEXRAD) data combined with onboard radar data in a graphical weather information system.

- Display of weather products in a GA cockpit was demonstrated by ARNAV using the Weather Hazard Information System developed under a cooperative agreement. Display concepts for retrofit and installation in a new cockpit also were developed.

Neural Networks for Pilots Who Fly Smarter

NASA is doing something to help pilots who find themselves flying severely damaged or malfunctioning aircraft—by developing new "smart" software that eventually will help aviators control and land disabled airplanes more safely.

The Intelligent Flight Control System (IFCS) project's ultimate goal is to demonstrate this revolutionary control concept and efficiently identify key aircraft stability and control characteristics using neural networks—and optimize aircraft performance in both normal and failure conditions.

Neural network software has the capability to "learn" by observing patterns in the data it receives and processes—and then initiating different tasks in response to new patterns. Simple neural network software has been in use since the 1960s in computer modems—but it has never been used in the safety-related aviation environment—until now.

In July 2002, the NASA F-15B Research Testbed performed a functional check flight equipped with instrumentation needed to test the Generation I IFCS. The IFCS flights using the NASA F-15B are the first demonstration of an online "learning" neural network, which can learn changes to baseline aircraft stability and control derivatives and upgrade the neural network representations.

A new fabrication technique with composite materials is an innovation that allows the composite to be shaped into the complex geometries needed for turbine vanes. This will enable the design of higher performance, cleaner, longer lasting turbine engines.

Objective 2.2 **Protect the Environment**

Protect local and global environmental quality by reducing aircraft noise and emissions.

Reducing Emissions

Among the chemicals produced during the combustion of aircraft fuel, two types have the most impact on human health and the quality of the environment—various nitrogen oxides (NO_x) that degrade local air quality as common “smog” and interfer with the ozone layer— and carbon dioxide (CO_2) that impacts the global environment by contributing to greenhouse warming. NASA efforts to explore emission reduction technologies will benefit the public in at least two ways:

- Reducing the overall impact of aviation operations on local air quality.
- Eliminating nearly all aircraft emissions that are a source of climate change.

The following FY 2002 accomplishments highlight NASA's research to Reduce Emissions.

Stronger Weaving for Turbine Vanes

Fiber-reinforced ceramic matrix composites offer advantages over metallic materials—particularly for aerospace and nuclear applications.

To improve strength and performance of aerospace turbine engines—a new fabrication technique developed at NASA enables use of fiber-reinforced ceramics for “first-stage” vanes in a gas turbine engine.

This is key because first-stage vanes are exposed to the highest material temperatures in a turbine engine as they direct the hot combustion gas flow toward the first stage of rotating turbine blades. One of the challenges for a ceramic composite vane has been shaping it to fit the complex geometry and structure of the sharp radius at the vane trailing edge.

This new fiber architecture innovation addresses the fabrication challenges presented at the vane trailing edge, and it provides composite-fiber architecture in the remaining regions of the vane that has been demonstrated in other turbine engine components.

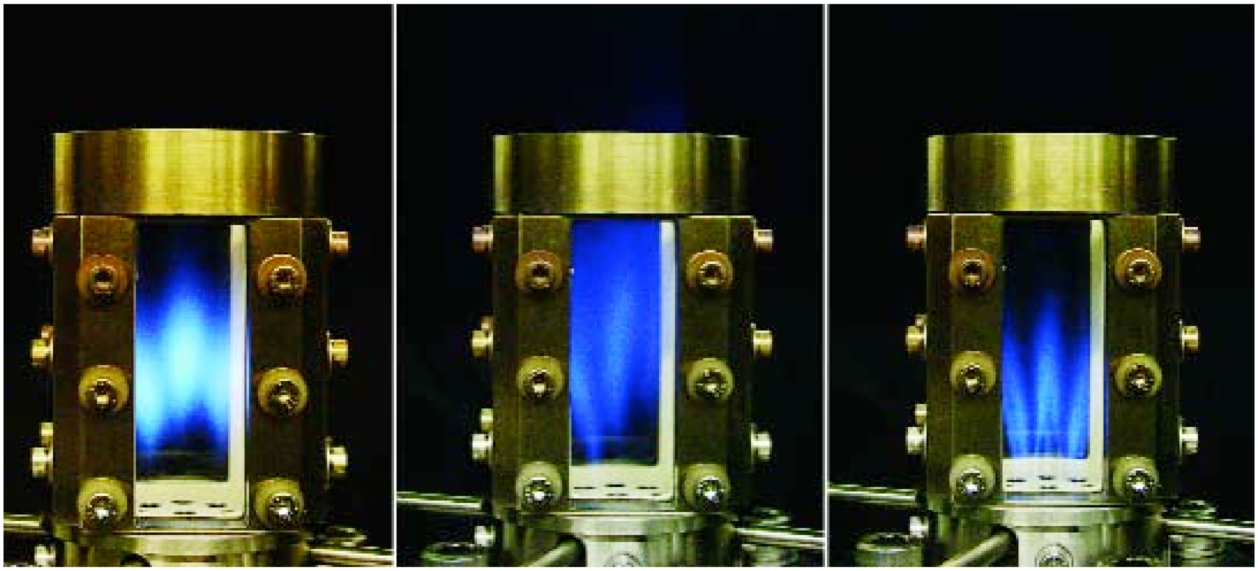
Developed as part of the Ultra-Efficient Engine Technology Program, a specially designed “Y-cloth fiber architecture” now provides a unique solution to this fabrication challenge.

Fuel Injection for the Intelligent Engine

In partnership with Goodrich Aerospace, NASA demonstrated a metal multipoint Lean Direct Injector (LDI) fuel injection concept for use in a gas turbine engine combustor. LDI technologies can help improve performance of aircraft turbine engines and reduce exhaust emissions.

The injector was made by Goodrich and tested in the CE-9 Flame Tube Combustion Test Rig at the NASA Glenn Research Center. Tests demonstrated an 81 percent reduction in NO_x emissions relative to the 1996 International Civil Aviation Organization (ICAO) Standard.

This is a major step towards an actively controlled combustor with embedded sensors and actuators that would be used in an intelligent engine that can adjust



NASA hydrogen air combustion experiment, performed at Sandia National Lab, demonstrates a cleaner burning fuel option (by eliminating CO_2) for future gas turbine engines and contributes to the OAT emissions reduction goal.

its fuel consumption for maximum efficiency. A silicon carbide version of the LDI is being fabricated by the Sensors and Electronic Branch at Glenn Research Center and will be tested in the CE-5 test rig.

Silicon carbide provides high-temperature capability and is the base structure for incorporating advanced micro-sensors and micro-electromechanical systems (MEMS) devices within the LDI injector assembly. Microvalve concepts using MEMS technology are currently in development.

Mix It Up to Beat Smog

Reducing NO_x emissions from advanced aircraft engines is a key objective of the NASA Aerospace Technology Enterprise and Ultra-Efficient Engine Technology (UEET) Program.

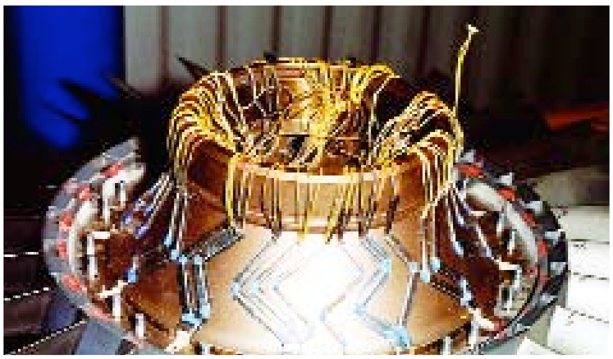
Separate tests using a sector rig and a lean-burning staged combustor Twin Annular Premixing Swirler (TAPS) mixer technology demonstrated up to a 67 percent NO_x reduction below 1996 ICAO standards. Temperatures and pressures used for the TAPS rig were typical of engines in service today. Testing at higher pressures (50:1 to 55:1 ratio) is planned at the Glenn Research Center Advanced Subsonic Combustion Facility.

Research will continue with the goal of reaching a 70 percent NO_x reduction in a sector rig by the end of FY 2003.

These low-emission sector combustor tests provide confidence that future combustors can be developed that are capable of meeting the goal of 70 percent NO_x reduction for the landing and takeoff cycle, for future commercial engines, reducing air pollution and smog in and around airport communities.

Pulsing Fuel Adds Life to Engines

To reduce environmental impact of aerospace propulsion systems, NASA is conducting extensive research with lean-burning (low fuel-to-air ratio) combustors. Lean-burning combustors have increased susceptibility



(Top) Compressor wired for data. (Bottom) Fan wired for data.

to thermo-acoustic instabilities, or high-pressure oscillations much like sound waves, that can cause severe high-frequency vibrations in the combustor. These pressure waves can significantly decrease combustor and turbine safe operating life. Suppression of these instabilities is an enabling technology for lean, low-emissions combustors.

Under the Aerospace Propulsion and Power Base Research and Technology Program, Pratt and Whitney, United Technologies Research Center (UTRC), and Georgia Institute of Technology partnered with NASA to develop technologies for active combustion instability control. Pressure oscillations are put into the system by pulsing the fuel—this cancels out oscillations produced by instabilities. Thus, the engine has lower pollutant emissions *and* longer life.

The team demonstrated high-frequency (greater than 500 Hz) instability suppression on a single-nozzle combustor rig at UTRC. This team is the *first* to demonstrate active control in an environment relevant to aircraft engines.

Continued work will apply these advanced technologies to future low-emissions combustors.

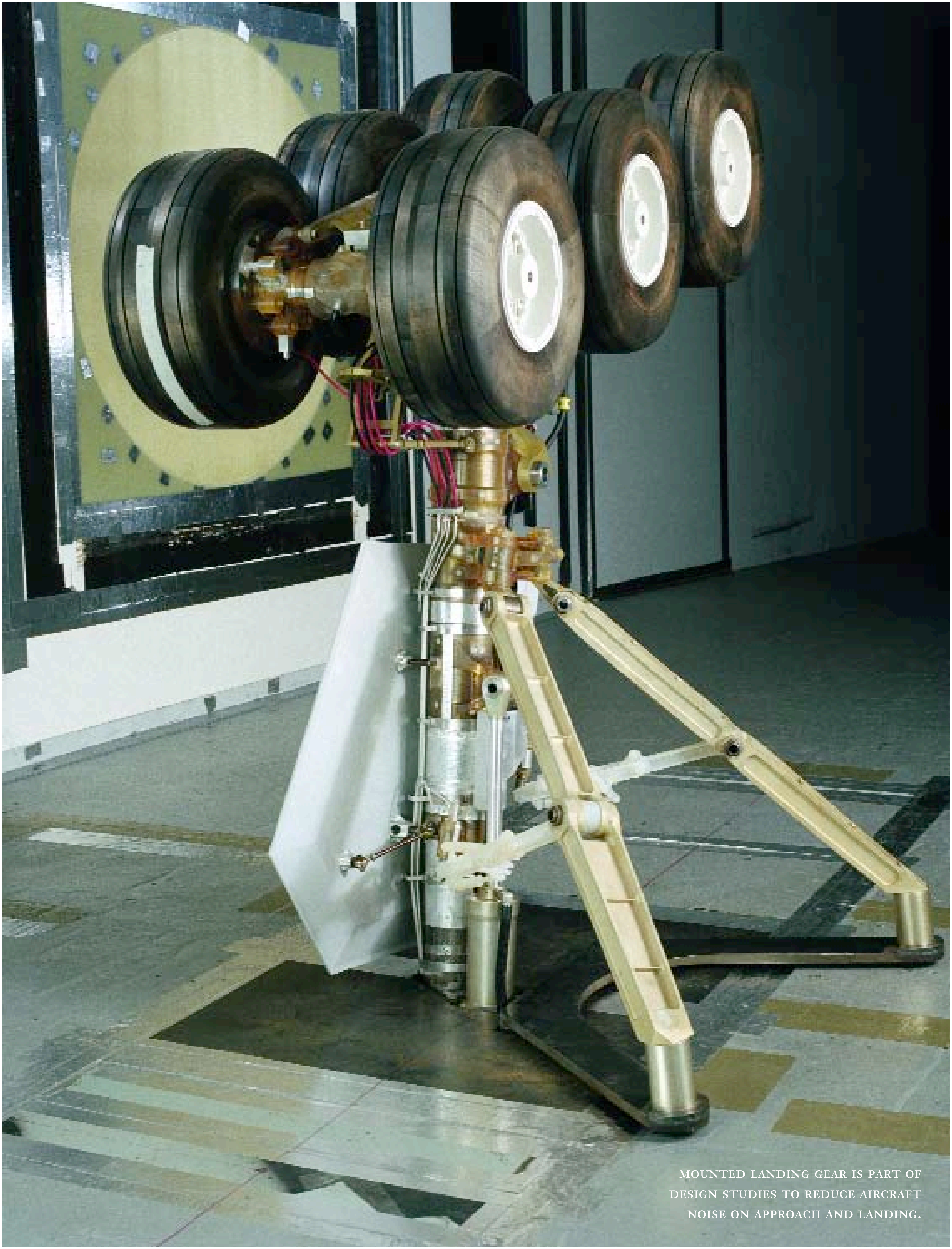
Putting the Brakes on Global Warming

Rather than simply reduce turbine-engine emissions, a NASA team is working to totally eliminate one pollutant—CO_2—through pioneering technology research directed towards hydrogen-powered aircraft of the future.

The Zero CO_2 Emissions Technology Team investigated two hydrogen-fueled aircraft approaches—gas turbine engines—and fuel cells. Analyses show both approaches are feasible using current technology. Research showed CO_2 emissions were eliminated and NO_x emissions were greatly reduced through development of a low-NO_x hydrogen fuel injector for turbofan engines.

Researchers also found lightweight tanks of fiber-reinforced polymer/clay “nanocomposites”—a potential breakthrough in hydrogen storage—helped reduce hydrogen permeability by two orders of magnitude, and a patent is pending on this technology.

Weight reductions of 20–30 percent are possible over metal tanks. Fracture toughness improved by 50 percent and strength by 40 percent. Power density improvements result from thinner, crack-resistant electrolytes that allow shorter, lighter fuel cell stacks. Partnerships with industry and academia have been an integral part of this project and show both the desire and need for such working solutions.



MOUNTED LANDING GEAR IS PART OF
DESIGN STUDIES TO REDUCE AIRCRAFT
NOISE ON APPROACH AND LANDING.

Reducing Noise

NASA is conducting a balanced effort to make major advances in noise reduction by 2007 and looking to high-impact technologies to achieve more substantial targets by 2022.

Reducing noise impact around airports—and confining air transport noise within compatible land-use areas—will benefit all the homes and businesses close to an airport. This will enable faster and more efficient growth in our nation's air system—and reduce constraints on where new airports and runways are located.

Understanding source noise mechanisms gained from computational, as well as experimental investigations, also will lead to discovery and optimization of noise reduction concepts to achieve the NASA 10-year, 10-decibel (dB) noise reduction objective.

The work completed in FY 2002 provides the foundation for future developmental eff o rts. The demonstrated new technologies—when incorporated into aviation systems—will result in an additional 2-dB noisereduction f rom the 1997 baseline for aircraft noise.

The following FY 2002 accomplishments highlight NASA's research to Reduce Noise.

Landing Gear Noise

Study of airframe system noise in FY 2002 revealed landing gear as the primary source of airframe noise, followed by flaps and slats. Technologies were developed to reduce landing gear noise by streamlining airflow around gear through use of structures such as a "virtual" gear fairing.

Workstation-based simulations were used to identify and document technology requirements for developing advanced operation procedures.

In addition to changes to the landing gear, later deployment of landing gear is considered as an operational modification. For flaps and slats, concepts such as main-element links, flap-edge blowing and porous-slat trailing edges show promise. These concepts will be initially pursued in the Quiet Aircraft Technology program. At the end of FY 2003 the projected component benefits will be assessed on an airplane testbed.

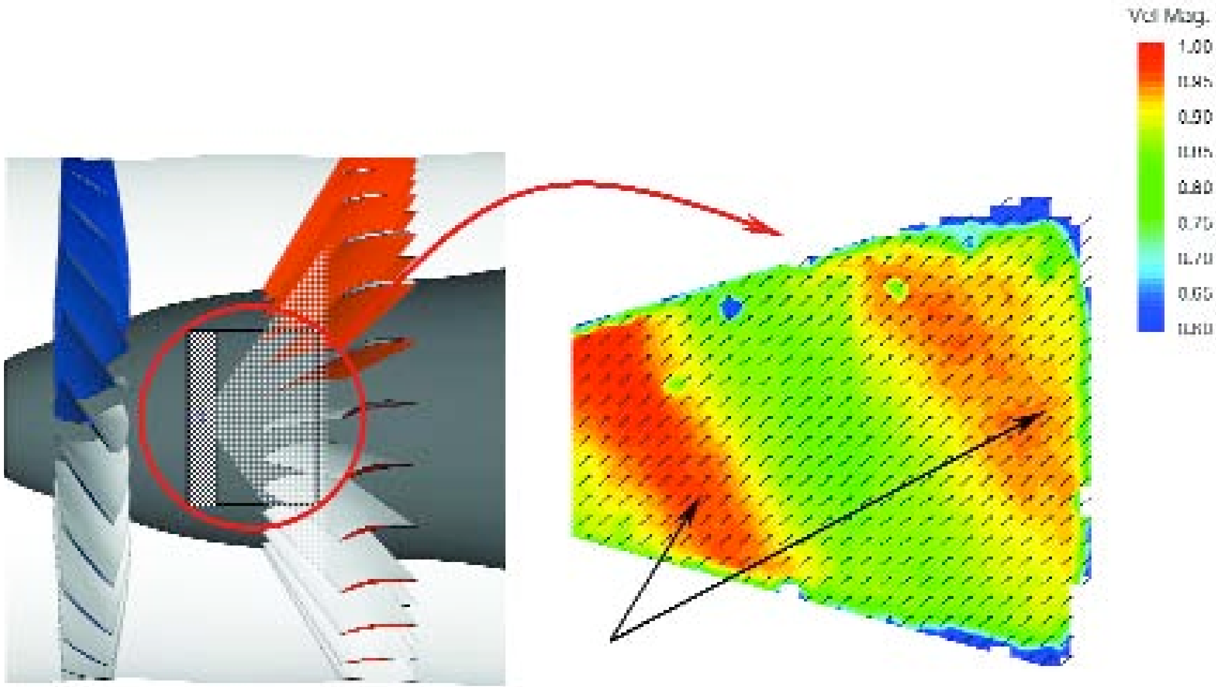
PIV Helps Designers Visualize Engine Noise

To understand fundamental mechanisms that cause noise in turbofan engines, an advanced flow-measurement technique, Particle Image Velocimetry (PIV), was used for the first time in FY 2002 to characterize turbulent airflow through fan and exhaust components.

The PIV technique uses a pulsed laser-light sheet to record positions of individual particles in a fluid at two points in time across a planar region of the flow.

This very accurate data, obtained with PIV, will help validate existing noise-prediction computer codes, and aid development of new Computational AeroAcoustics (CAA) codes to be delivered as part of the NASA Quiet Aircraft Technology Program in 2005.

A variety of technical challenges were resolved to use PIV techniques in fan and exhaust nozzle flow fields such as modification of model-scale engine nacelle



Fan flow measurements made using particle image velocimetry technique to improve designs for low noise engines.

hardware allowing high-speed photography of laser-illuminated particles. The resulting data, together with noise prediction computer codes under development, will be used to analyze, design and optimize new concepts for engine noise reduction.

Tools to Predict Aircraft Noise

System-level noise assessments are used to determine which technologies will provide the most leverage in reducing community noise impact. During FY 2002, NASA awarded a contract to define the code architecture for an Advanced Vehicle Analysis Tool for Acoustics Research (AVATAR), an improved version of a tool known as the Aircraft Noise Prediction Program (ANOPP).

With AVATAR, noise prediction accuracy will be greatly improved execution time and reduce code maintenance cost. AVATAR will use reengineered ANOPP code, incorporate the capabilities of ANOPP, and add capabilities to predict advanced aircraft configurations such as the Blended Wing Body concept. A beta version of AVATAR has been delivered for internal NASA use and testing (includes several significant improvements over ANOPP).

Quieter Landings Ahead

A literature review provided a list of operational noise reduction techniques, from which the continuous descent approach (CDA) was selected as the focus of further research.

Although CDA aims to reduce noise in areas further from the runway, other techniques may be integrated into the approach flight path to help reduce noise closer to the end of the runway. An impact study has shown that arrival demand is the main factor affecting runway throughput for each of the noise reduction techniques studied.

During low arrival demand periods, CDA does not appreciably impact runway throughput. Additional research will address new techniques for enabling CDA to be used successfully in moderate to high demand periods and locations.

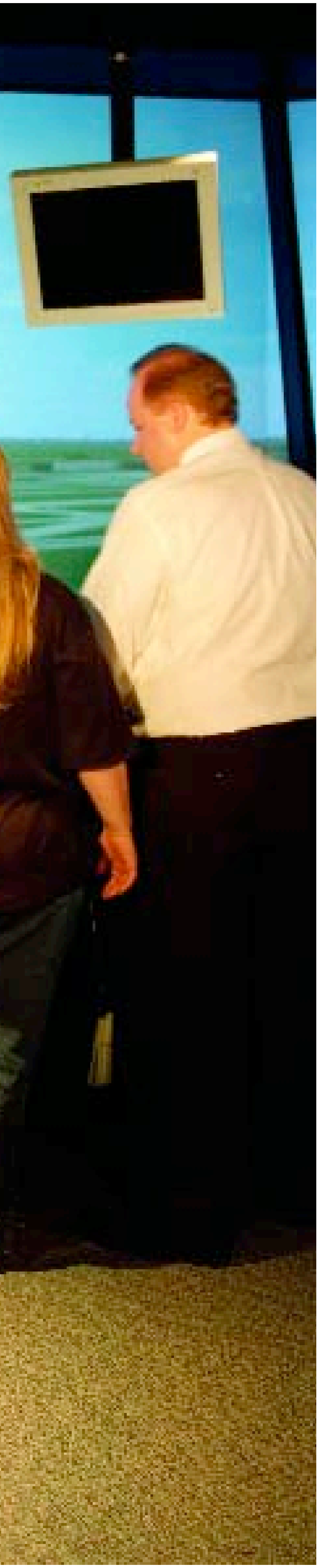
Quiet for the Movie

Ongoing work in improving passenger and crew environment noise has demonstrated broadband performance of "smart foam" as both a passive and active concept. Purdue University has shown the reduced transmission loss from optimized fiberglass. Embedded structural damping, foam materials, and overall system configurations are expected to reduce noise by up to 4 decibels.

The continued development of embedded electronics and distributed autonomous controller technology also will make active control cheap and effective for use in specific trouble areas where excessive noise exists.

Full-scale evaluation of noise reduction technologies.

A simulation demonstrating SMS and TMA interoperability was conducted in the FutureFlight Central simulator at Ames Research Center with tower controllers from Dallas/Ft. Worth, Memphis, and Norfolk airports. Representatives from several air carriers (FedEx, UPS, Northwest Airlines, United Airlines, and American Airlines) also participated.



Objective 2.3 **Increase Mobility**

Enable more people and goods to travel faster and farther, with fewer delays.

Although the events of September 11 have temporarily reduced demand on our nation's air system—delays are expected to return as demand for passenger and cargo flights increase. In cooperation with the FAA—NASA is developing new system concepts and airspace systems technologies:

- Improving gate-to-gate air traffic management and control processes by is developing decision-support system technologies to assist air traffic controllers, pilots, and aircraft operators in using airspace more efficiently.

- Identifying and developing new concepts, to increase future air transportation capacity and developing innovative modeling techniques.

Decisions Decisions

Selecting the best sequence of airport runways to use for landings and departures has become very complex—as demands on our National Airspace System have grown. Improved decision tools and concepts that can help safely automate the selection process are in development at the NASA Ames Research Center.

In FY 2002, the FutureFlight Central simulator at Ames tested the capability of two decision support tools to help reduce arrival and departure delays. The Surface Management System (SMS) and Traffic Management Advisor (TMA) tools—were used to switch runways from departures to arrivals. In the simulation, two runways were used for departures and a third runway used for arrivals. A human Traffic Management Coordinator (TMC) then decided when to switch one runway from departures to arrivals. Timelines of arrival and departure schedules were the most helpful tools for these decisions. The TMC also found SMS information, particularly timelines, helpful in managing departure runway balancing.

Better Flow Helps Safety and Cuts Delays

A new Traffic Flow Automation System (TFAS) decision support tool for system-wide prediction of air traffic sector loading was developed and evaluated in FY 2002. The intent is to use higher fidelity models of a tool known as the Center TRACON Automation System (CTAS) to predict future sector loadings. CTAS is a set of tools designed by the FAA and NASA to help air traffic controllers manage increasingly complex air traffic flows at large airports. The tools in CTAS benefit air traffic controllers by reducing stress and workload, and benefit air travelers by reducing delays and increasing safety.

The demonstration of TFAS capabilities represents the first time that CTAS algorithms and models have been used to predict traffic flow for all air traffic in the NAS simultaneously. Data obtained during operation of this initial traffic management capability at Ames shows that sector loading accuracy is improved. The Ames hp j6700 Compute Farm was used to process all air traffic in the NAS simultaneously. The data demonstrates that, in general, the TFAS provides more accurate predictions of sector loading than current tools.

Increased Air Mobility Gives Everyone a Lift

Conceived as a safe alternative to free people and products from the limitations of today's ground and air transportation systems—the Small Aircraft Transportation System (SATS) concept will increase reliable air access to virtually any community in America.

NASA has selected the National Consortium for Aviation Mobility (NCAM) as its partner in a joint venture to develop and demonstrate SATS Project operating capabilities and enabling technologies. NCAM members include a broad range of industry, university, state and local aviation authority groups from across the United States. NASA and NCAM, along with the FAA, will conduct research and development proof-of-concept activities. These studies have the potential to increase use of small community and neighborhood airports without requiring changes to control towers, radar installations, and increased land use for added runway protection zones.

In FY 2002, SATS project partners established a baseline framework for project management and systems engineering efforts needed to develop, evaluate and demonstrate new operating capabilities that are key to the overall SATS concept. Over time—SATS technologies will provide benefits to commuter and air carrier operations as well.

Internet in the Sky

Fundamental improvements in aircraft communications and information services are required to support SATS goals for better air access across America. To satisfy these communications requirements—NASA, the FAA, and industry partners—developed an "Airborne Internet."

The Airborne Internet is a revolutionary, integrated Communications, Navigation and Surveillance (CNS) system that delivers aviation information services in an Internet-like manner to aircraft and ground users via a high-speed digital communications network.

Developed to support SATS goals for improved intercity door-to-door mobility, Airborne Internet features include a robust high-capacity aviation information system for air traffic control and safety advisories; worldwide compatibility; seamless peer-to-peer connectivity; high bandwidth and data rates; and confirmed delivery notification.

In partnership with industry and the FAA—NASA led the development of the Airborne Internet. Now complete to a high level of technology maturity, the next stage is underway and involves transferring this technology to a newly formed Airborne Internet Consortium—known as SATSLab—for further evaluation and commercialization.

artist concept of a small personal-use jet aircraft from
the small aircraft transportation system (sats) project.

THE ALTAIR UNMANNED AERIAL VEHICLE (UAV), BUILT BY GENERAL ATOMICS AERONAUTICAL SYSTEMS, INC. FOR NASA, IS POISED FOR FLIGHT AT GA-ASI FLIGHT TEST FACILITY AT EL MIRAGE, CALIFORNIA.

Objective 3.2 **Support National Security**

Enhance the Nation's security through aeronautical partnerships with DOD and other Government agencies.

In FY 2002, innovative technology was developed to enable high data rate space communications from small ground stations, and to demonstrate the application of nanotechnology for chemical sensors and high strength composite materials.

Staying Airborne Longer

The NASA Environmental Research Aircraft and Sensor Technology (ERAST) program was established in 1994 under a Joint Sponsored Research Agreement to help accelerate development of Uninhabited Aerial Vehicle (UAV) technologies for scientific and commercial applications.

NASA developed the Predator-B/Altair UAV to meet the requirements of the NASA Earth Sciences Enterprise for a future airborne science platform that could remain aloft at high altitudes for very long time periods without refueling.

The Predator-B/Altair is the next generation of reconnaissance and sensor platform developed from the Predator vehicle. The events of September 11, 2001 accelerated this effort with the Predator-B aircraft. In December 2001, the USAF performed a Predator-B mission to meet the NASA mission-profile metric. Flight above 40,000 feet for more than 24 hours without refueling was demonstrated.

This demonstration was also a testament to a strong partnership. Working together DOD and NASA were able to quickly solve a number of issues to meet both national security needs and scientific goals.

Research Testbed for Flight Experiments

Using the NASA F-15B Research Testbed to demonstrate and mature new technologies helps facilitate a rapid transition of technology into defense, scientific and industry applications.

The mission of the F-15B Research Testbed is to provide NASA, industry, and universities with a long-term capability for flight testing of aerodynamic, instrumentation, propulsion, and other flight research experiments. The primary objective is to conduct flight research at lower cost to enable validation of design tools and techniques.

During FY 2002, the following F-15B experiments were completed for users including the Defense Advanced Research Projects Agency (DARPA), NASA, and various academic institutions:

- Portable Neutron Spectrometer
- Flight testing of Propulsion Flight Test Fixture
- Laminar Flow Experiment #3
- Supersonic Shaped Boom Demonstration baseline flights

DARPA, U.S. Airforce, Boeing X-45A UCAV at NASA Dryden.

X-45A Unmanned Flights and Taxi Tests

The goal of the X-45A Unmanned Combat Air Vehicle (UCAV) technology program is to demonstrate operation of high-performance autonomous vehicles and autonomous ground and flight control laws. The first X-45A vehicle flew in May 2002 and the second X-45A flew in November 2002.

The X-45A UCAV is an autonomous low-observable radar signature vehicle with a deeply embedded propulsion system. Boeing built two X-45A vehicles as part of the DARPA Advanced Technology Demonstration UCAV program.

NASA provided design of the autonomous ground (taxi) control laws along with collision avoidance and airspace operation strategies. The objectives of taxi tests were to analyze guidance, navigation, control, and subsystem performance for the purpose of validating design tools and subsystem models.

Autonomous taxi control capabilities were required by the DARPA, DOD and USAF customer to enable X-45A to maneuver on its own up to takeoff and for post-flight operations.

The X-45A is a major demonstration program for future weapon systems. NASA expertise in ground and flight test techniques has been critical to success with the X-45A. Activities such as X-45A help NASA maintain its core competencies in advanced UAV technology.

Smart Simulations Help C-17 Globemaster Pilots

Integration of the Intelligent Flight Control System control laws into a C-17 simulation in FY 2002 was a first for use of a neural network flight control system in a quad-redundant flight control environment.

Neural network software provided pilot control at levels comparable to or better than existing C-17 control laws at specific flight conditions. Two NASA and one Air Force test pilot from the C-17 test force flew the simulation to ensure that Neural Network software flew comparable to or better than the existing C-17 control law. The pilots flew a standard set of C-17 evaluation maneuver cards to determine simulation suitability.

Positive pilot comments on the simulation were received from NASA and Air Force pilots. Next steps include continuing the simulation efforts and on-board learning neural network and failure mode insertion. Later, Generation 2 neural network software for the C-17 will be developed.

C-17 taxing for take-off.

ARTIST RENDERING OF REUSABLE LAUNCH VEHICLE CONCEPT.

Space Launch Initiative Theme

Revolutionizing our space transportation system to significantly reduce costs and increase reliability and safety will open the space frontier to new levels of exploration and commercial endeavor.

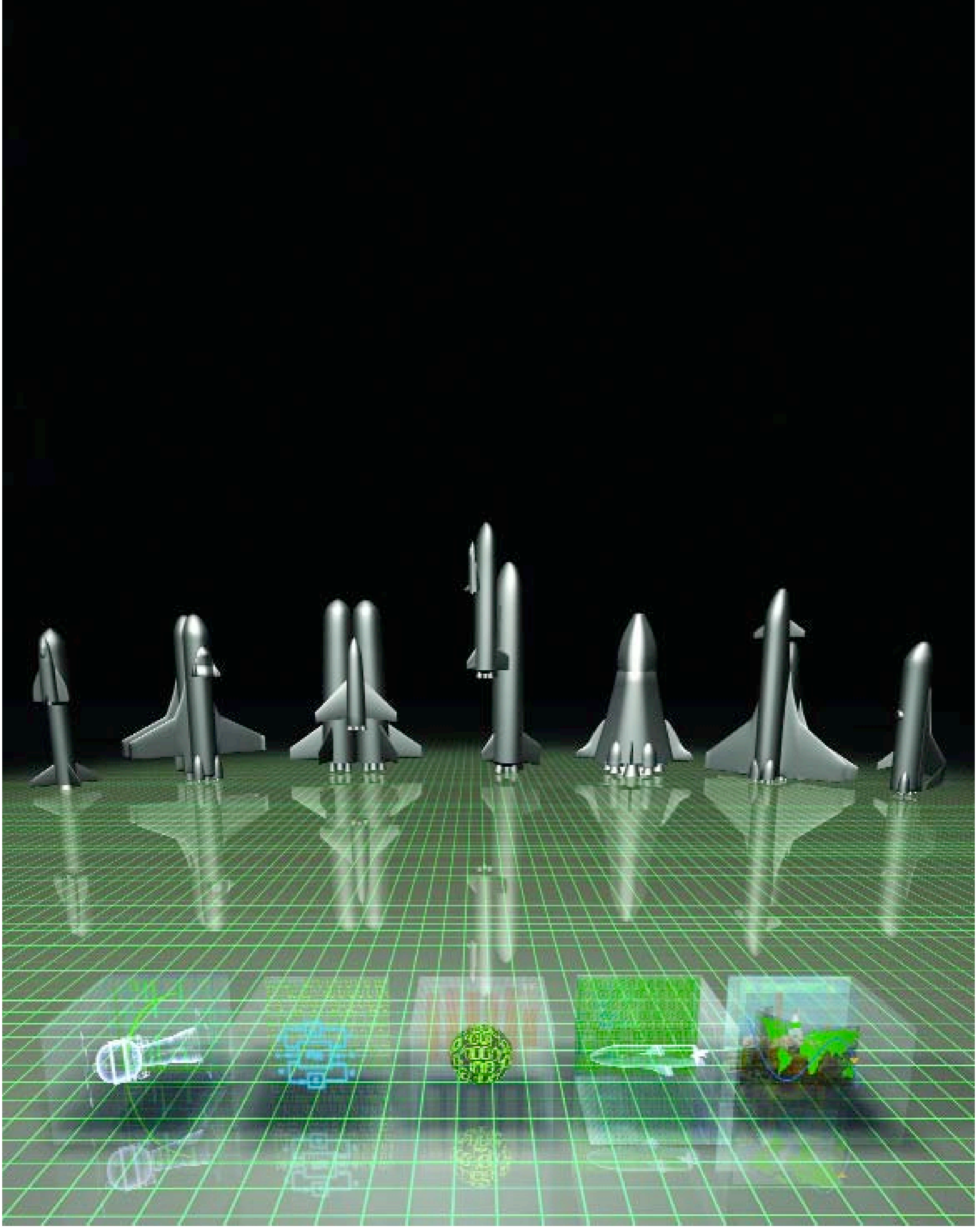
With the creation of the Integrated Space Transportation Plan (ISTP), NASA has defined a single, integrated investment strategy for its diverse space transportation efforts.

By investing in a sustained progression of research and technology initiatives, NASA will enable the design and development of future generations of reusable launch vehicles and in-space transportation systems that will overcome present Earth-to-orbit challenges.

This will result in less costly, more frequent, and more reliable access to our neighboring planets and eventually to the stars beyond our solar system.

The following pages report key accomplishments the Aerospace Technology Enterprise achieved toward realizing this goal. Expanded write-ups, images, and videos can be found on the supporting website at: *http://www.aerospace.nasa.gov*

ARTIST CONCEPTS FOR NEXT GENERATION LAUNCH VEHICLES.



Objective 8.2 **Mission Safety and Affordability**

Improve the safety, affordability, and reliability of future space transportation systems.

NASA is making substantial headway on new technologies to deliver payloads to Low-Earth Orbit at 100 times less than the cost of current technology and to reach a similar reduction in the cost of placing payloads in higher orbits by 2025.

Space Launch Initiative Architecture

Under the new NASA Integrated Space Transportation Plan released in early FY 2003, the Space Launch Initiative (SLI) will focus on the Orbital Space Plane and Next Generation Launch Technology, including third-generation Reusable Launch Vehicle (RLV) efforts.

The Orbital Space Plane is designed to provide a crew-transfer capability and to ensure access to and from the International Space Station. The Next Generation Launch Technology Program funds developments in areas such as propulsion, structures, and operations for the next-generation RLV.

A new Integrated Space Transportation Plan (ISTP) is designed to benefit the International Space Station, Space Shuttle, and NASA science and research objectives. The new ISTP dedicates more resources to the Space Station program; provides additional funding to extend the life and enhance the safety and reliability of the agency's orbiter fleet; boosts funding for science-based payloads and research; and restructures NASA's Space Launch Initiative, originally designed to identify next-generation reusable launch vehicle technology.

The new ISTP reflects important changes to NASA's five-year budget plan, but keeps costs within the original 2003 fiscal budget.

A crucial component of the new ISTP is the development of a crew transport vehicle. The concept of an Orbital Space Plane reflects NASA's need to ferry Space Station crewmembers and to ensure that a capability exists to get the crew home if there is an emergency. The concept will be the immediate objective of the new SLI research efforts.

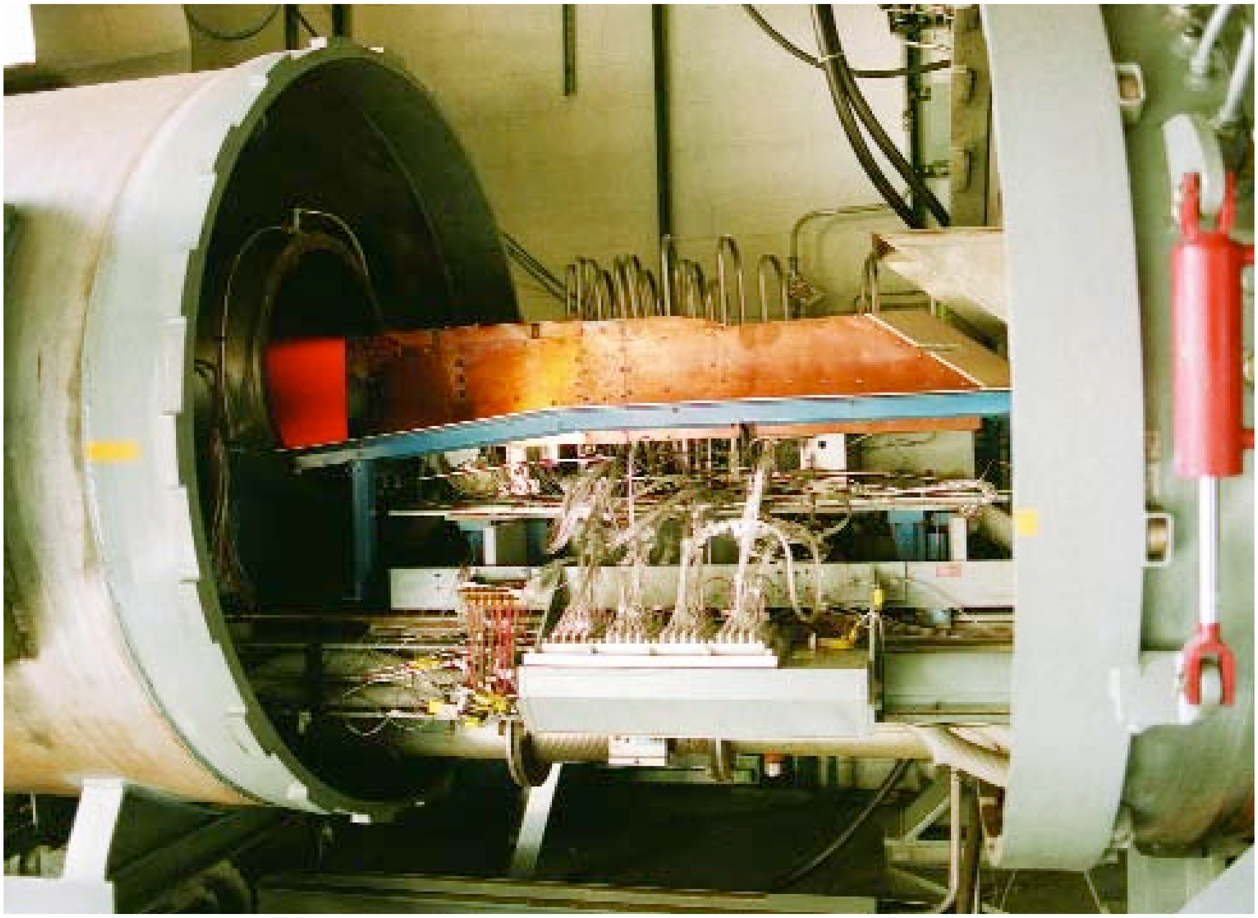
The Orbital Space Plane is beneficial on several levels—it is based on existing technologies and therefore lowers risk and is more affordable. It will replace the Space Shuttle as the primary crew transport vehicle, freeing the orbiter fleet to focus on heavy cargo delivery.

SLI will continue to identify future reusable launch vehicle technology through a new Next Generation Launch Technology program, investing money in propulsion, structures and other key areas.

Rockets Breathing Air

A prototype for an innovative NASA "air-breathing" rocket engine—that could revolutionize air and space travel in the next 40 years—reached a major milestone in FY 2002—fully three months earlier than planned.

The air-breathing rocket engine gets its initial power from special rockets in a duct that captures air, which helps it perform 15 percent better than conventional



Test firing of an air-breathing rocket engine.

rockets. At twice the speed of sound, the rockets turn off and the vehicle relies on oxygen in the air to burn fuel. As the vehicle reaches 10 times the speed of sound, the engine converts back to a rocket to propel the craft into orbit.

Spacecraft using these engines would be reusable and capable of takeoff and landing at airports—and ready to fly again in days.

Being developed by the NASA Integrated System Test of an Air-breathing Rocket (ISTAR) program—the program plans to test an air-breathing vehicle at six times the speed of sound, demonstrating all modes of engine operation.

System requirements review on the flight test engine was completed in July 2002. ISTAR is part of the NASA effort to make future space transportation safer, more reliable—and much less expensive than it is today.

Polymer Composites Can Take the Heat

For 20 years, NASA and industry have partnered in the technology of using lightweight textile composites. Historically, the biggest barriers to use of composites in commercial jets have been the cost and its tolerance to damage.

Composites used in space structures must remain strong at higher temperatures than with jet engines. Space propulsion components must withstand temperatures of 650°F or more. But use of high-temperature composites in space applications could save 30 percent of component weight—so there is great benefit to using these materials.

Under a Boeing/NASA cost-shared project—a new polymer was developed that exhibits the high-temperature characteristics for use at 650°F. The manufacturing process also will reduce the component costs by 50 percent—and reduce maintenance due to the exceptional long-term durability and damage tolerance.

A variety of components were made with this polymer using a Resin Film Infusion process. This process involves injecting resin into a "pre-form" of woven or braided fiber, which had been limited to fabricating lower temperature polymer materials. This work will reduce acquisition and maintenance costs for advanced space systems—and will lead to similar savings in military and commercial aircraft engines.

New No-Pressure Adhesive

New fabrication adhesives developed by NASA will allow efficient production of composite structures—without the use of expensive industrial autoclaves. In addition, this adhesive process permits fabrication of large composite structures.

This improved fabrication process can be used for products needing high strength-to-weight ratio characteristics available from composite structures. Commercial applications include aerospace and automobile manufacturing as well as other industrial uses. Based on a series of non-autoclave high-flow adhesive materials containing Phenylethynyl terminated imides (PETI-8), composites now can be processed with vacuum bag and oven-only techniques that do not require external autoclave pressure. Early testing of the PETI material also shows excellent adhesive strength when bonding titanium.

Future work is underway to study the characteristics of this adhesive when used with composite structures. If this new adhesive material works as predicted, it can significantly reduce manufacturing costs and facility requirements.

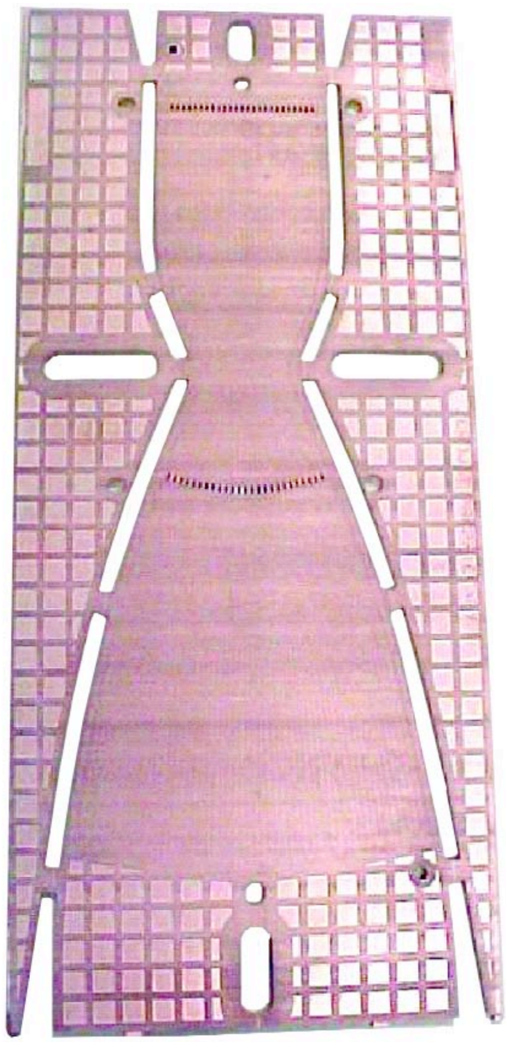
New Alloy Has Remarkable Qualities

A revolutionary copper-based alloy (GRCop-84 Cu-Cr-Nb) may soon replace current state-of-the-art materials in "regeneratively-cooled" rocket engines because it will result in longer engine life, higher performance, improved safety and lowered maintenance costs.

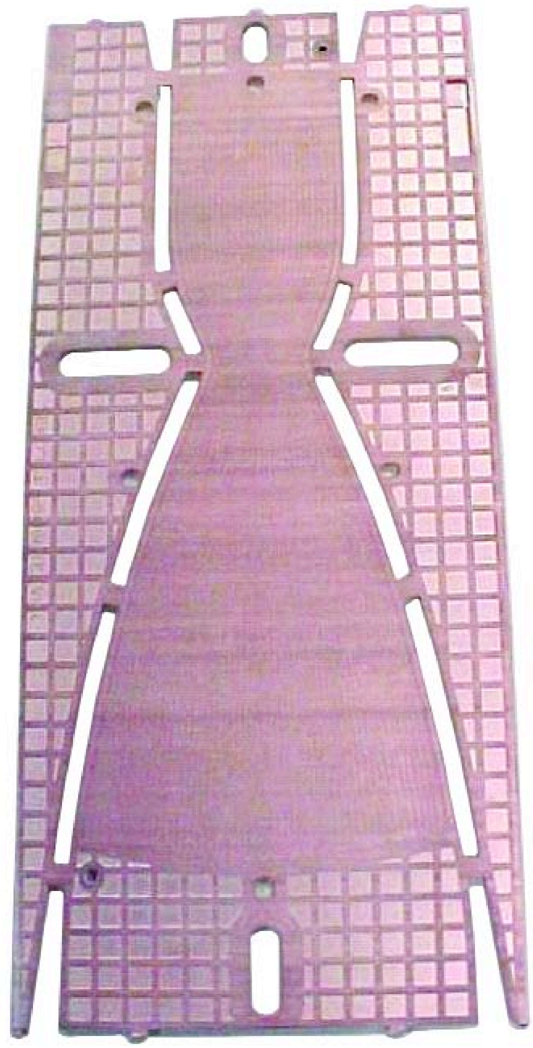
In 2002, more than 1,400 pounds of the copper alloy has been processed into copper sheet and plate in support of the Co-Optimized Booster for Reusable Applications (COBRA) engine—a liquid oxygen/hydrogen single "preburner-staged" combustion main engine for reusable launch vehicles.

This new alloy will substantially improve key properties of industry standard materials that have been used since the 1960s. Weight reductions of more than 10 percent for combustion chamber designs, increased temperature capability, longer life, reduced maintenance, and higher reliability will result.

In 2003, this material will be used in subscale platelet chambers for testing in a rocket combustion chamber that is undergoing combustion and active cooling. Work on the alloy by NASA, industry, and academia



Manifold side



Hot gas side

Platelet Technology Liner—Platelet liners are made by stacking sheets of GRCop-84 that has been machined with the desired shapes for cooling channels and other features and bonding them together. Sections are formed and joined to make the completed Main Combustion Chamber.

is paving the way to a low-risk, high-gain transition for all major rocket engines.

COBRA Main Engine

The COBRA engine is designed to provide a 100-mission lifespan with maintenance checkups after 50 missions. Its liquid oxygen/liquid hydrogen main engine design produces 565,000 pounds of thrust at vacuum and contains a single liquid-liquid fuel-rich preburner, high-pressure turbopumps, low-pressure turbopumps, and a channel-wall nozzle. The engine's liquid-liquid preburner provides a key enabling technology for future engines by lowering temperatures and "smoothing" engine ignition. A single-preburner cycle provides inherent safety by eliminating one high-pressure burner.

The COBRA Team fabricated and proof-tested a 40 percent scale milled channel-wall nozzle. The nozzle was structurally tested at pressures up to four times higher than normal operation, validating the design of the nozzle which will improve safety, cost, and reliability, while reducing fabrication time from four years to one year. The milled channel-wall nozzle is designed for ease of manufacture and is less susceptible to coolant leakage, currently a problem for a tube-wall design rocket engine. A single-piece liner eliminates hot gas wall joints and a liquid oxygen coolant feature eliminates the need for a traditional heat exchanger.

Historically, high-pressure pumps are one of the most difficult items to develop. COBRA uses mature Space Shuttle Main Engine (SSME) alternate design turbopumps. Several key technologies eliminate possible SSME failure modes: the platelet injectors eliminate 909 parts, the channel wall nozzle construction eliminates 1,080 tubes, and the liquid oxygen-cooled nozzle eliminates a catastrophic SSME failure mode. The jet-engine-type Engine Health Management System enhances safety with continuous diagnostics and reduces engine turnaround time between flights. In 2002, the prototype preburner was completed through the Critical Design Review level and a subscale preburner was successfully tested.

The option to extend work on the COBRA prototype engine was not exercised as part of the period of performance that ended September 30, 2002. At this time the SLI Program decided to focus its propulsion development activities on a liquid oxygen (LOX)/Hydrocarbon engine. The program determined after extensive data analysis that the LOX/hydrocarbon engines provided greater risk reduction potential for a new reusable launch system.

Spaceflight by Candlelight

The NASA Ames Hybrid Combustion Facility successfully tested an alternative rocket fuel that may increase operational safety and reduce costs over current solid fuels. Other tests at Stanford University have shown that a new paraffin-based fuel has a burn rate three times greater than other hybrid fuels. The new paraffin-based fuel could eventually be used in space shuttle booster rockets. The first successful test in a series of 40 runs took place in September 2001.

Two years of collaboration between Stanford University and NASA Ames Research Center have led to development of a non-toxic, easily handled fuel made from a paraffin substance similar to common candle wax.

The byproducts of combustion of the new wax fuel are carbon dioxide and water—unlike conventional rocket fuel that produces aluminum oxide and acidic gasses such as hydrogen chloride.

A hybrid rocket using this fuel could be throttled—or have its thrust varied—including being shut-down and later restarted—offering a wide range of options compared to solid rocket motors of today that do not have those options.

Pint-Sized Leak Detectors Just Right

The Advanced Space Transportation effort needs improved leak detection capabilities to reduce explosion risk, improve safety, and reduce vehicle-operating costs.

Leak detection is important to avoid explosive conditions that could harm people and damage space vehicles. Dependable vehicle operations require timely and accurate leak measurement; and improved leak detection techniques are needed to meet the Mission Safety Objective of reducing the incidence of crew loss by a factor of 40 within 10 years as well as reducing costs by a factor of 10.

Existing leak detection systems are large, require a pumping system and large amounts of power—or do not work in the environment of space. This has limited the capability to detect leaks in a wide range of applications; and there are often no space-qualified systems that meet NASA needs.

In response, a NASA-led team in 2002, developed a postage-stamp sized hydrogen leak detection system that meets NASA and industry needs, and has customized it for use in many applications.

Significant technical challenges were overcome: miniaturizing sensor size and electronics; operating reliability in inert environments; and providing adequate sensitivity to give early hazard warnings.

Measuring Vehicle Health

The Integrated Vehicle Health Management (IVHM) project focuses on technology that determines the "health" or fitness level of a launch vehicle in order to increase safety and reduce operations and maintenance costs.

IVHM uses advanced information technologies—software, hardware, communications, and sensor technologies—to increase the safety of operations, reduce vehicle turnaround times, and eliminate unnecessary maintenance tasks.

Concepts for embedding IVHM monitoring sensors into aerospace structural materials have been developed—and preliminary tests have been performed. These concepts may enable the development of embedded sensor systems for widespread structural health management of future generations of aerospace vehicles.

New fiber-optic concepts also have led to a major reduction in sensor complexity and a 50 percent cost reduction for embedding sensor systems in aerospace structural materials. Laboratory evaluation and development of existing concepts along with further development of new concepts for embedding sensors is underway.

Reusable Launch Vehicle

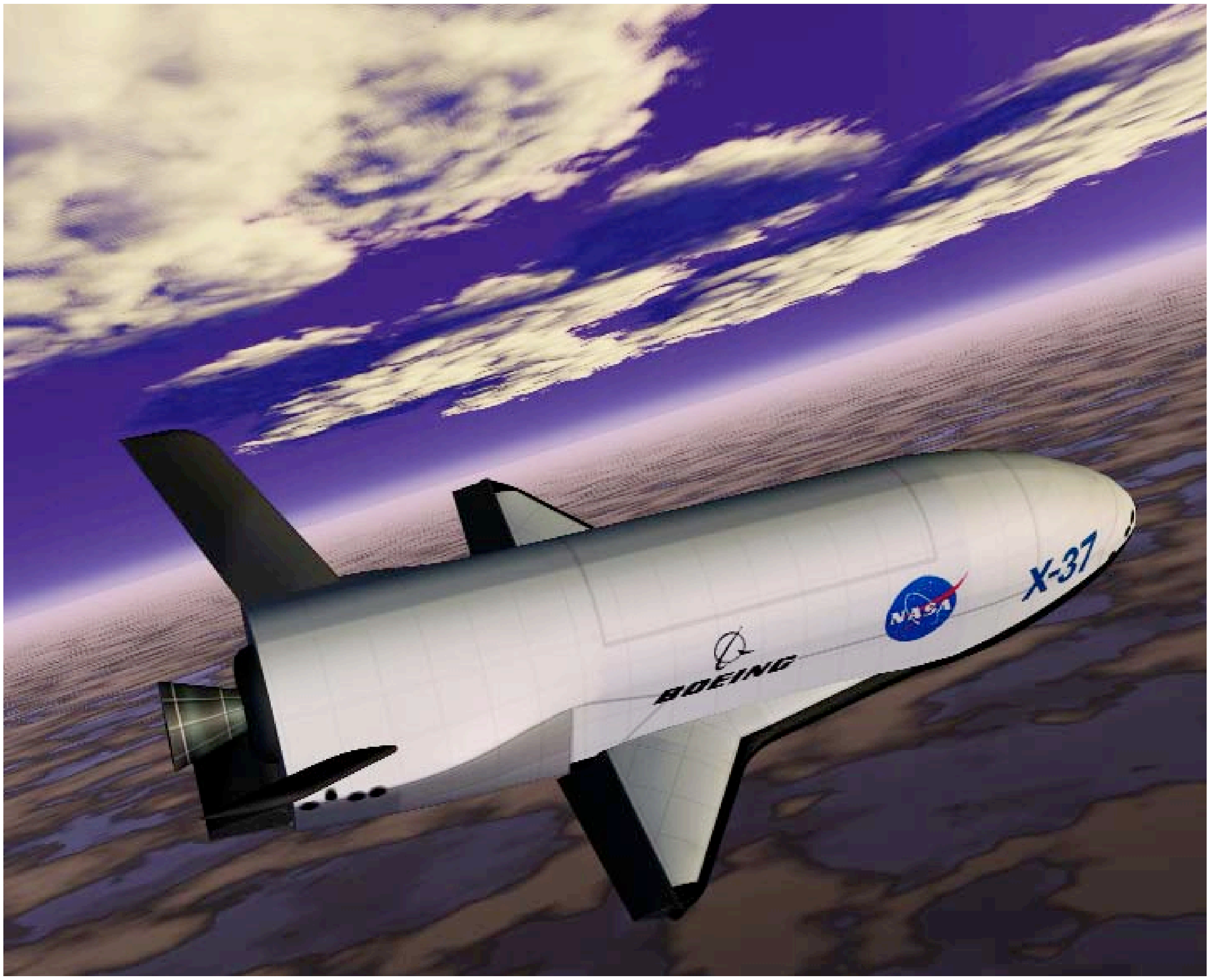
Risk reduction and development activities conducted by the 2nd Generation RLV program culminated in evaluation of competing second-generation reusable launch vehicle architectures and technologies in FY 2002.

Architecture definition studies focused the available trade space from over 100 candidate architectures to the 15 most promising candidates, identified the key technology drivers for a 2nd Generation RLV, and prioritized the technology development needs.

Propulsion system requirements definition and conceptual design studies were performed in support of these architectures. These studies focused the selection of the thrust class and fuel for the booster stage, second stage, and on-orbit auxiliary rocket engines and led to the decision to prioritize further rocket engine work on reusable kerosene engines to support a booster stage of an RLV.

Airframe design evaluations included assessments of hot aeroshell/integral tank structures and a demonstration of a self-reacting friction stir welding process for metallic cryogenic tanks. Additional technology development activities were conducted in integrated vehicle health management, flight mechanics, operations, and power systems.

Investments in space transportation launch technologies will be continued in the Next Generation Launch Technology Program—with decision points outlined in the future on whether to implement a new launch vehicle.



Testbed for dozens of advanced concepts that could pioneer the way for future reusable launch vehicles.

ION ENGINE MOUNTED IN A JPL TESTBED.

Objective 9.5 **Support for Space Exploration**

Develop innovative approaches and concepts to inform future decisions concerning systems, infrastructures, and missions for the human and robotic exploration of space.

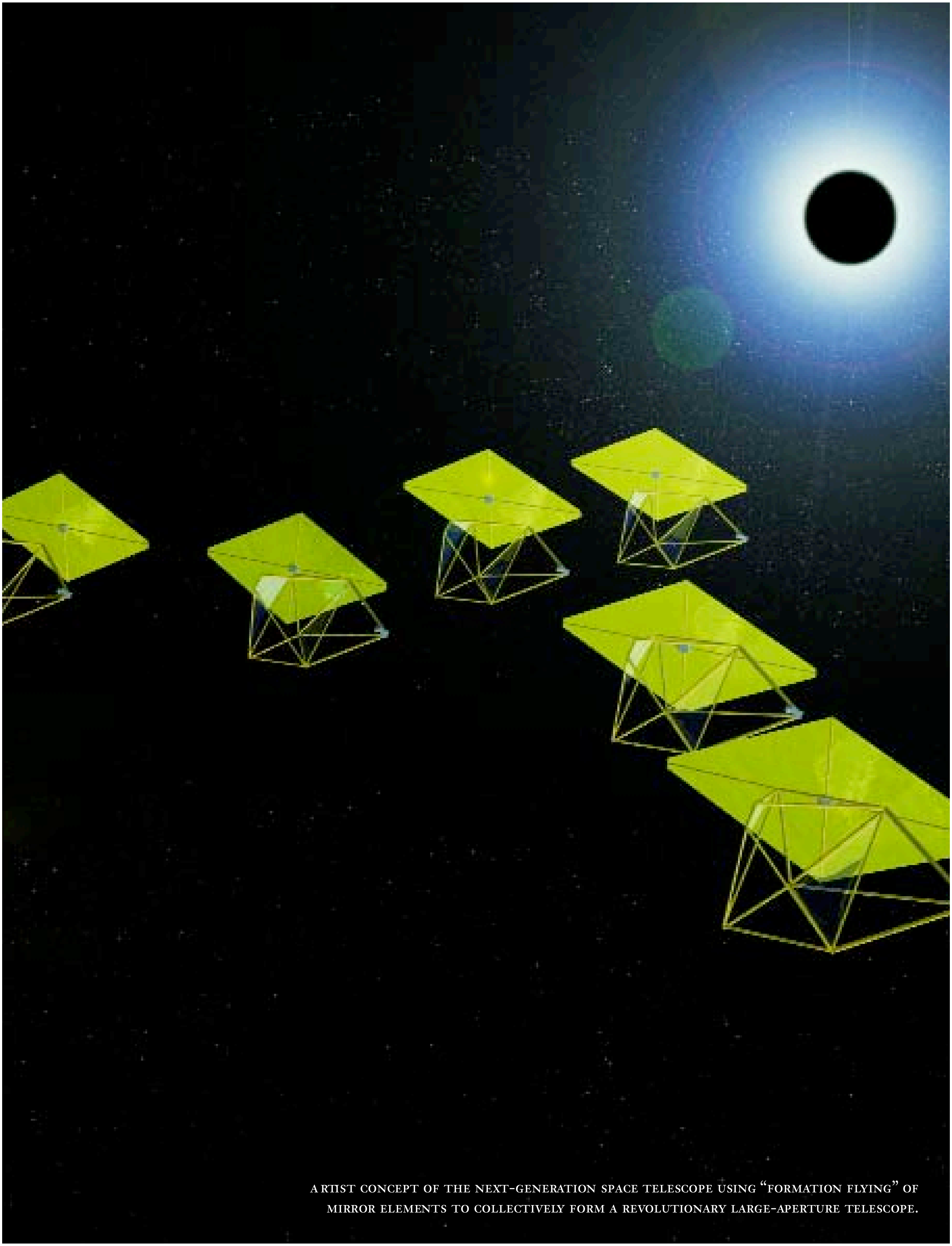
This objective aims to develop light, rapid space propulsion systems that will make travel times for long planetary missions dramatically shorter than today. These advances will be achieved through use of small systems for travel to the planets and using breakthrough propulsion technologies to reach other stars within a human lifespan. Although begun as an Aerospace Technology Enterprise program, responsibility for this objective is now within the space and flight support theme.

Ion Engine Streams Ahead

The NASA Glenn Research Center is evaluating high specific impulse ion thrusters for potential outer planet and interstellar missions. Unlike chemical rocket engines that burn large amounts of solid or liquid fuels in a few short minutes—an ion engine emits a gentle stream of electrically charged atoms—for a period that could last years or even decades.

Use of ion engines could reduce travel times for long interplanetary and interstellar missions because once "turned on" these engines typically are operated continuously—which serves to continually increase vehicle speed—as long as the ion stream continues to flow. In FY 2002, NASA completed and demonstrated a 10-kilowatt ion engine, which is designed for use in nuclear-electric propulsion systems. The high-power ion engine used titanium ion optics that produced four times the power and a 62 percent greater specific impulse than the current state-of-the-art ion engine.

Two high-power ion optics approaches were designed, manufactured, and tested. Next steps involve increasing power output above the 10-kilowatt level.



ARTIST CONCEPT OF THE NEXT-GENERATION SPACE TELESCOPE USING "FORMATION FLYING" OF MIRROR ELEMENTS TO COLLECTIVELY FORM A REVOLUTIONARY LARGE-APERTURE TELESCOPE.

Missions and Science Measurement Technology Theme

New and innovative approaches to system design and technology development will be needed to build the aerospace systems of the future. These new systems will depend on technology and disciplines still in their infancy.

Developing the broad knowledge base and information architecture needed to design advanced aerospace systems is a crucial first step. Creating the advanced engineering tools and techniques that promote high-confidence design and construction of new systems also is required. As part of this effort, the NASA Aerospace Technology Enterprise is developing fundamental new technologies to assist other NASA Enterprises in accomplishing their strategic objectives.

Technology transition planning and change management processes are used to effectively support incorporation of new technologies into NASA missions. These technologies will enable collection, analysis, distribution, and development of new scientific data, discoveries, and information in a more rapid and efficient manner than ever before.

The following pages report key accomplishments the Aerospace Technology Enterprise achieved toward realizing this goal. Expanded write-ups, images, and videos can be found on the supporting website at: *http://www.aerospace.nasa.gov*

EXAMPLE OF CTV (CREW TRANSFER VEHICLE) WITH DIFFERENT WING CONFIGURATIONS.

Objective 10.1 **Mission Risk Analysis**

Improve the capability to accurately assess and manage risk in the synthesis of complex systems.

Success in assessing and managing risk can help us find critical equilibrium among cost, performance, and schedule, while protecting the safety of our people and investments. Research and development activities to ensure mission success are built upon technologies that identify and eliminate risks; capture, integrate, and utilize knowledge; and provide an intelligent response to hazards. NASA will define the tools and techniques to manage risks and customize solutions for its various missions.

Vehicle Redesign—During Flight Simulations

NASA is working on a promising approach to reduce the overall time and cost to develop aerospace vehicles—by enabling vehicle design changes to be made during flight simulations using high-end computing tools and advanced information management techniques.

During FY 2002, real-time piloted simulations of a future Crew Transfer Vehicle (CTV) were completed. These simulations used integrated Computational Fluid Dynamics, flight test and wind tunnel data. Astronaut pilots provided ratings of the vehicle performance and handling qualities of the concept CTV simulation.

This system allows real-time evaluations by astronauts of the handling qualities of proposed aerospace vehicles—while the vehicle concepts are still on the drawing board. The system also functions as a virtual laboratory for remote collaboration among design groups, which helps reduce design cycle time through speedier integration of the engineering products developed in the design process.

The Virtual Laboratory was used for collaboration among engineering groups focused on design, fluid dynamics, control system, and handling qualities. Three NASA Centers at four sites across the country were involved in the collaborative design effort. Advances in experimental vehicles, flight testbeds and computing tools will lead to development of revolutionary new designs.

USING TECHNOLOGY DEVELOPED BY THE OFFICE OF AEROSPACE TECHNOLOGY, THE MARS RECONNAISSANCE ORBITER WILL USE HIGH-POWER MICROWAVES TO ANALYZE THE PLANET'S SURFACE FOR SIGNS OF WATER.

Objective 10.2 **Science Driven Architectures and Technology**

Create system concepts and demonstrate technologies that enable new scientific measurements.

Driven by future mission needs, NASA will research, develop, and evaluate a range of fundamental technologies that enable new and improved missions and new science measurement capabilities. NASA will validate new technologies to facilitate their infusion into missions at minimal cost and risk.

Seeing Red on Mars Reconnaissance Orbiter

In 2005, NASA plans to launch a powerful new scientific orbiter, the Mars Reconnaissance Orbiter (MRO). This MRO mission will focus on analyzing the surface in an effort to follow tantalizing hints of water detected in images from the Mars Global Surveyor spacecraft, and to bridge the gap between surface observations and measurements from orbit.

As part of MRO, the Mars Climate Sounder (MCS) instrument will sample the planet's atmosphere using an infrared detector. This detector consists of nine un-cooled thermopile linear arrays. The MCS instrument will sample atmosphere at 20 altitudes simultaneously—and measure pressure, temperature, gas composition and dust. These instruments were engineered to be one-eighth of their original weight—and now perform using a quarter of the initial power specification.

Rovers Get Freedom to Do Real Science

In 2003, two new Mars rovers will be on the way to the red planet. With greater mobility than the Mars Pathfinder rover, these explorers will trek up to 100 meters across the surface in a Martian day. Each rover will have more freedom—or autonomy—to perform routine functions and operations than ever before and carry a sophisticated set of instruments to allow it to search for evidence of liquid water that may have been present in the planet's past.

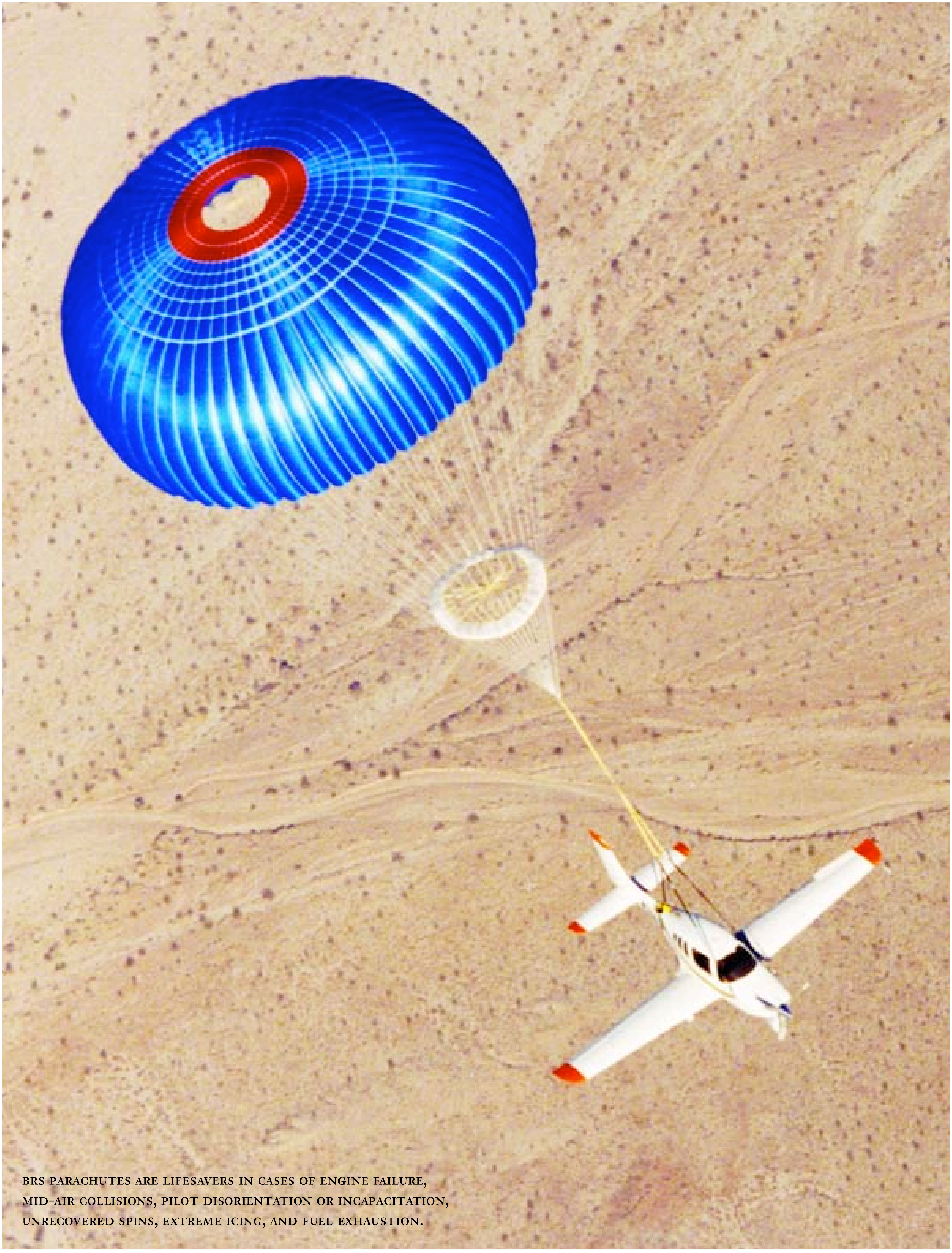
Both autonomy and collaborative workspace technologies for the new rovers were demonstrated in simulations and field tests. Many of these technologies will be used for Mars Exploration Rover (MER), and several will be used for planetary exploration missions such as the 2009 Mars Science Laboratory.

The application of this technology would enable rapid response based on unexpected events or opportunistic (unplanned) science, which are often inherent in long-range traverse scenarios. Elements of these high-level autonomy capabilities will be tested and evaluated in the upcoming MER mission, with full infusion anticipated for the Mars Science Laboratory mission.

Virtual Tools Help MER Team Collaborate

Another advanced information technology to be demonstrated on the MER mission is a new collaborative workspace developed to help streamline mission operations. The collaborative workspace—known as "MERBoard"—allows geographically dispersed scientists, engineers, and mission operators to interactively develop mission plans and monitor mission status. The workspace functions like an electronic bulletin board that the science team can use to ask the rover to acquire interesting data and targets along its route. The MERBoard also provides a common framework for naming targets and communicating science goals that will enable the mission team to work together more efficiently.

Collaborative engineering environments can substantially reduce the time needed to conduct tests and plan mission operations. Images can be marked up on a large plasma screen and reviewed in real time on other MERBoards connected to the network.



BRS parachutes are lifesavers in cases of engine failure, mid-air collisions, pilot disorientation or incapacitation, unrecovered spins, extreme icing, and fuel exhaustion.

Innovative Technology Transfer Partnerships Theme

While NASA technology benefits the aerospace industry directly, creative applications of this technology have contributed to ongoing work in other fields including the environment, surface transportation, and medicine.

Commercial uses and transfer of technology to American businesses, other NASA programs, and to federal agencies exercises the full breadth and depth of NASA's assets: technological skills and expertise, large-scale and complex systems management experience, and advanced scientific research programs in cooperation with industry and academia. NASA's technology transfer processes help our industrial economy, provide new benefits to the American people, and supply advanced technologies needed in other federal agencies and organizations.

The following pages report key accomplishments the Aerospace Technology Enterprise achieved toward realizing this goal. Expanded write-ups, images, and videos can be found on the supporting website at: *http://www.aerospace.nasa.gov*

Objective 3.3 **Extending Benefits to Society**

Improve the Nation's economic strength and quality of life by facilitating the innovative use of NASA technology.

NASA technologies are available to industry for commercialization support in the U.S. economy. NASA works closely with large and small businesses to facilitate the innovative use of NASA technology.

Calibration is Faster and Cheaper

A unique calibration-loading system that offers dramatic time and cost savings in wind tunnel testing has been developed at NASA Langley Research Center. Calibration time is reduced from 3–4 weeks to a matter of hours—and saves about $6,000 per calibration.

Called the Single-Vector Balance Calibration System (SVS)—the calibration loading system is integrated with formal experimental design techniques developed at NASA. During SVS calibration, a mathematical model is derived that is used in wind tunnel tests of aircraft models to estimate the aerodynamic loading.

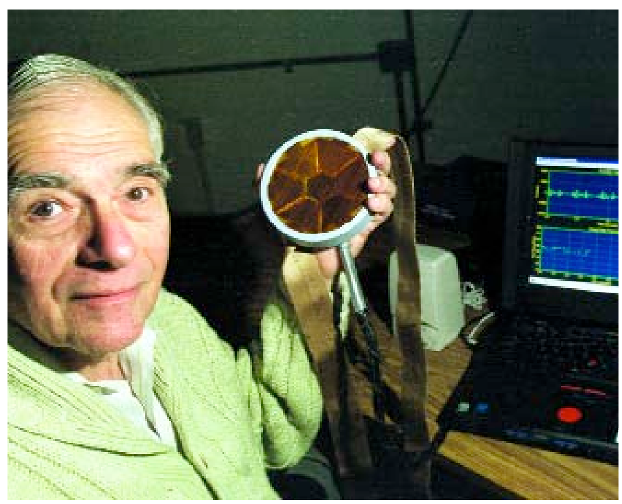
To develop flight vehicles, models undergo wind tunnel tests to study the direct force and moment measurement of aerodynamic loads. An instrument known as a "force balance" captures these measurements during testing. The calibration process for this balance instrument is critical to production of high-quality force data.

Traditional, manual dead-weight calibration techniques require pulleys, cranks, cables, and levers and frequently take weeks to perform. In contrast, SVS can perform calibrations with many fewer components so it has fewer sources of systematic error. This technology was recently licensed to Modern Machine & Tool Co., Inc.

Monitor Baby's Heart at Home

A physician working in a remote area spurred development of a passive fetal heart monitor concept—so measurements of fetal heart rate and a related non-stress test could be made by women at home—without help from a medical professional.

The underlying technology was developed at the NASA Langley Research Center, which sponsored initial testing at Eastern Virginia Medical School and the Morehouse School of Medicine. Licensed to Baby Beats, Inc., of Spokane, Washington, the company anticipates that prototype systems will be ready for clinical testing soon. Founded by the physician who turned to NASA for help with this problem—Baby Beats expects its systems will become commercially available following FDA approval.



Allan Zuckerwar of Langley's Advanced Measurement and Diagnostics Branch, is holding the material used for wing surface measurements. Because it is flexible, it is ideally suited to fit over the curved surface of a maternal abdomen for fetal testing.

The enabling technology for this commercial development began in a NASA aeronautical research program—thin electro-active film was used to measure pressures associated with airflow over the wings of wind tunnel models.

Versatile Piezoelectric Actuators

Known as the piezoelectric effect—some materials will produce electric impulses when the material is pressed, squeezed, and stretched. Supply electric current to these materials—and they contract or change shape as well. This technology produces controlled motion when stimulated by voltage—and it generates an electrical potential when stretched or strained.

Macro-Fiber Composite (MFC) technology—from the NASA Langley Research Center—was used recently to produce a new high-performance, cost-competitive, and easily manufactured piezoelectric strain actuator. The MFC actuator may be embedded or attached to the surface of a flexible structure for distributed deflection, vibration control, and strain sensing. The MFC actuator was exclusively licensed to the Smart Material Corporation for sales in foreign markets. Its intended use is for vibration dampening, noise reduction, and shape-changing applications.

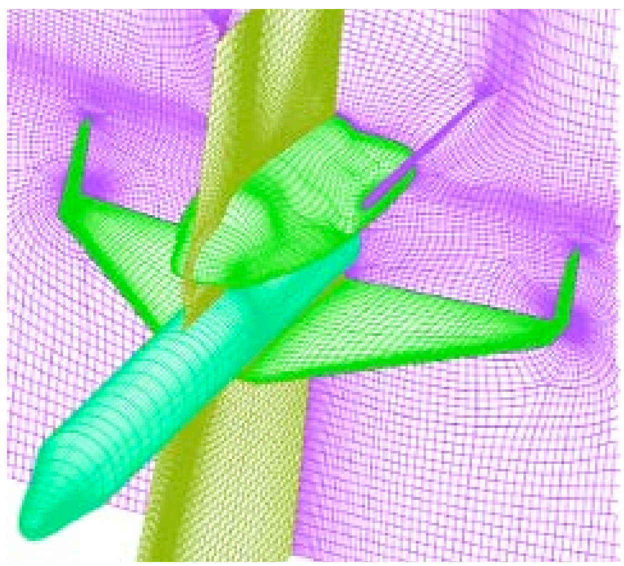
New Tools Help CFD Users

Cart3D is an aerodynamic computational simulation tool developed jointly by NASA and New York University. This tool has been licensed and will be available to designers and engineers providing an automated, accurate computer-simulation tool suite that streamlines conceptual and preliminary analysis of new and existing aerospace vehicles.

Before Cart3D—the basic computational tool used in analyzing designs of airplanes and spacecraft—was a hand-generated grid layout—and it took months or even years to generate complex models. Cart3D may help revolutionize computational fluid dynamics—the computer simulation of how fluids and gases flow around an object of a particular design.

Cart3D automates grid-generation to a remarkable degree, enabling even the most complex geometries to be modeled 100 times faster than before. Fusing cutting-edge technology from the fields of mineralogy, computer graphics, computational geometry and fluid dynamics—Cart3D gives engineers a new industrial geometry processing and fluids analysis capability that is unique in its level of automation and efficiency.

The NASA Ames Commercial Technology Office licensed Cart3D for commercialization to ICEM CFD Engineering, a subsidiary of ANSYS, Inc. The licenses will help extend Cart3D beyond aerospace applications and into new industries such as automotive, electronics, turbo-machinery and industrial process simulation.



Program Development Company's GridPro technology was used to create the conceptual design of a two-stage-to-orbit launcher.

Periodically, NASA is called on in emergencies and unusual situations to lend its expertise outside of its usual research and technology development. This support is requested for everything from airplane crashes and natural disasters to nonprogram activities with the military, other agencies, and industry.

The following sections provide highlights of that special support during FY 2002.

Flight 587 Accident Investigation

November 12, 2001, an American Airlines Airbus 300-600R aircraft crashed after takeoff into Jamaica Bay, New York. During the accident, the vertical fin and rudder separated from the aircraft while it was still in flight.

These structures are made primarily of graphite-epoxy composite materials. Experts in composite structures and materials and aerodynamics specialists from the NASA Langley Research Center were contacted to help the National Transportation Safety Board (NTSB) determine what caused the vertical fin and rudder to depart from the aircraft in the accident.

NASA experts are assisting NTSB by conducting structural analyses of the vertical fin and rudder at the accident loading conditions—and they are studying the structures to identify how the vertical fin and rudder failed.

Nondestructive evaluation and detailed photographic surveys have been performed to help identify precisely where the structures failed. Comparing results of these analyses with the failed parts should yield a definitive explanation. Once the root cause is understood, steps will be taken by the NTSB to help ensure that this sort of accident does not happen again.

NASA support for Flight 587 accident investigation.

As of March 19, 2003 NTSB Investigation Update, all investigative groups are continuing their work. The investigation's Structures Group is working with NASA and Airbus to arrange a static lug test to be conducted in Hamburg, Germany this spring. The left-side rear main attachment lug from an A310 tail fin box panel will be tested to demonstrate the behavior of the lug under tensile load conditions to which the fin of Flight 587 had been exposed during the accident sequence.

New Aviation Security Capabilities

As a result of the World Trade Center events in 2001, NASA has been working to enhance aviation security and aerospace technologies. As part of these efforts, NASA has performed several flight research demonstrations using advanced datalinks to a monitoring system that transmits live pictures from inside a jetliner and downlinks "black box" recorder contents from airplanes in real time.

Sponsored by the NASA Aviation Safety Program, quick-turnaround experiments determined the feasibility of using existing and near-term communications links to perform new, security-focused services.

In November 2001, aircraft performance data and cockpit video from the NASA B-757 were downlinked using an existing aircraft directional S-Band telemetry link. In December 2001, a NASA/Honeywell team leveraged VHF Datalink Mode 2 (VDLM2) technology now under development to demonstrate remote black box and cockpit audiovisual surveillance concepts from the NASA Learjet to a ground station located at the NASA Glenn Research Center.

In January 2002, a joint effort by NASA, ARINC, Teledyne, and Flytimer successfully demonstrated remote black box, panic button and remote cockpit audiovisual surveillance concepts using the Glenn Research Center Learjet. The VDLM2 datalink was also used, but in a different configuration suitable for air transport operations flying at higher altitudes.

Members of the NASA Aerospace Technology Enterprise, are recognized by their peers, and other organizations, through numerous honors and awards.

These honors and awards help validate the level of work accomplished by the Enterprise and provide clear indication and affirmation of the skills and expertise of the people in the Aerospace Technology Enterprise. Congratulations are in order for the individuals and programs listed here—and for the efforts of colleagues and coworkers who helped make these honors and awards possible.

- **Daniel Guggenheim Medal.** Richard T. Whitcomb, Langley Research Center (LaRC) retiree, for seminal contributions in aeronautics, including the development of the area rule, supercritical airfoil, and winglets concepts, which are the basis for modern aerodynamic design.

- **(Virginia) Peninsula Engineers Council, 2002 Peninsula Engineer of the Year.** Awarded to Dr. Bruce J. Holmes.

- **(Virginia) Peninsula Engineers Council, 2002 Doug Ensor Young Engineer of the Year.** Awarded to Ms. Anna-Maria McGowan.

- **American Society of Mechanical Engineers (ASME) Medalist.** Dr. Leroy S. "Skip" Fletcher, for outstanding leadership in engineering achievements in aeronautics and astronautics, particularly in the area of thermophysics and thermal control in spacecraft.

- **ASME 2001–2002 Fellows.** Neil Anderson, recognized for impressive contributions to the progress of transmission and gear design and applications during the past 20 years including 24 published papers. Neil's research and contributions at NASA Glenn Research Center (GRC) in bearing and gear steels, transmission efficiency predictive modeling, and traction drives provided valuable tools for designers.

- **AIAA Inducted to the rank of Fellow:** Mr. Charles Miller III and Richard G. Culpepper (Ret.) of LaRC, J. Victor Lebacqz of NASA HQ, and Mr. Arthur G. Stephenson and Ann F. Whitaker of Marshall Space Flight Center (MSFC).

- **American Institute of Aeronautics and Astronautics (AIAA) sustained service awards:** Dr. Leroy. S. "Skip" Fletcher of Ames Research Center (ARC), Mr. Jerry N. Hefner and Mr. Ernest V. Zoby of LaRC, and Mr. David A. Throckmorton of MSFC.

- **AIAA, Aerospace Power Systems Award.** Mr. Ronald J. Sovie of GRC for a lifetime of personal contributions in the guidance and management of advanced space power technology research and development, including the development of a foundation for a national nuclear space power capability as Deputy Program Manager for the SP-100 program.

- **AIAA Hampton Roads Section, 2002 Engineer of the Year.** Awarded to Dr. Bruce J. Holmes.

- **Presidential Early Career Award.** Awarded to James Crawford of LaRC received the for Scientists and Engineers to further his research in the Global Tropospheric Experiment.

- **2002 AIAA Atmospheric Flight Mechanics Conference Best Paper.** Awarded to Dryden Flight Research Center (DFRC) engineers Ronald J. Ray, Brent R. Cobleigh, M. Jake Vachon and Clinton St. John's for their paper: *Flight Test Techniques Used to Evaluate Performance Benefits during Formation Flight*.

- **AIAA Distinguished Service Award.** Awarded to Dr. Leroy. S. "Skip" Fletcher of ARC.

- **Golden Web Award, International Association of Web Masters and Designers.** Awarded to the Ames Educational web site "Robin Whirlybird on her Rotorcraft Adventures."

- **American Helicopter Society, Howard Hughes Award.** Presented to the Langley Tiltrotor Aeroacoustics Code System Development Team of Casey Burley, David Boyd, Tom Brooks, Henry Jones, Devon Prichard, and Kristin Roberts, LaRC, honored for their outstanding improvement in fundamental helicopter technology.

- **Fellow of the American Helicopter Society.** Due to his accomplishments in the field of helicopter flight, Dr. William G. Warmbrodt of ARC was honored with the rank of Fellow.

- **Institute of Electrical and Electronics Engineers (IEEE)**, with the **Judith Resnik Award.** Suresh M. Joshi, LaRC, was honored for outstanding contributions to space engineering within the fields of interest to IEEE.

- **International Conference on Computational Engineering and Sciences, T.H.H. Pian Medal.** Ivatury S. Raju, LaRC, for distinguished contributions to computational methods in fatigue and fracture of metals and composites with particular relevance to aerospace engineering.

- **Virginia Polytechnic Institute and State University, Academy of Engineering Excellence.** Paul Holloway, former Langley Center Director, inducted for sustained and meritorious engineering and leadership contributions.

- **AIAA, Aerodynamics Award.** Richard Campbell, LaRC, for meritorious achievement in the field of applied aerodynamics, recognizing notable contributions in the development, application, and evaluation of aerodynamic concepts and methods, most notably the development and implementation of the Constrained Direct Iterative Surface Curvature methodology for rapid aerodynamic design.

- **Society for the Advancement of Material and Process Engineering (SAMPE), First place, outstanding paper by SAMPE member at 2002 SAMPE Symposium in Long Beach, California.** Awarded to Brian W. Grimsley of LaRC, Pascal Hubert of Old Dominion University in Virginia, Roberto J. Cano of LaRC, Xiaolan Song of Virginia Tech, R. Byron Pipes of the College of William and Mary in Virginia, and Alfred C. Loos of Virginia Tech, for a paper entitled *Effects of Amine and Anhydride Curing Agents on the VARTM Matrix Processing Properties.*

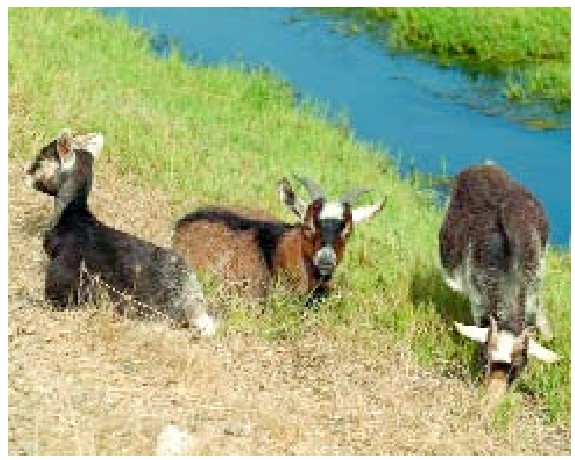
- **Acoustic Emission Working Group (AEWG) Fellow.** William H. Prosser was recognized for outstanding professional distinction and continued significant contributions to the AEWG and for advancements in the areas of acoustic emission in research, education, applications, instrumentation, or administration.

- **R&D 100 Awards.** The GRC Numerical Propulsion System Simulation, a propulsion system simulation software application—and for their work on an art-restoration technique using atomic oxygen, is the recipient of two prestigious awards presented annually by R&D Magazine for the 100 most technologically significant new products of the year.

- **Eric Reissner Medal.** Deepak Srivastava, NASA ARC scientist, earned the prestigious award presented by the International Conference on Computational Engineering and Sciences for using a computer to simulate molecular carbon "nanotubes"—so small they cannot be seen with a conventional microscope.

- **2002 Software of the Year Award.** Presented to Michael Aftosmis and Dr. John Melton of NASA ARC, and Professor Marsha Berger of the Courant Institute, New York University, by NASA Inventions and Contributions Boards for their joint development effort of Cart3D, an aerodynamic simulation tool.

- **Environmental Protection Agency 2002 Environmental Achievement Award.** Presented to NASA ARC, for goats munching "stubborn" vegetation and workers mulching land-scaping debris along with reducing pesticide and herbicide use. In 2002, NASA Ames reduced pesticide and fertilizer use by 98 percent compared with the previous year. The center also recycled all of its landscaping debris by composting, which saved an estimated $60,000 in disposal costs. In addition, Ames reduced the overall volume of herbicide distributed, used herbicides that are less toxic, and maintained drought-resistant, native vegetation. A group of 13 goats patrols certain areas to control "hard-to-deal-with" vegetation. "Goats are goats—they eat just about anything," said Jon Talbot, project manager for South Bay Maintenance. NASA Ames has invested in both high tech and low tech solutions to fulfill its mission and help protect the environment.



Goats munching 'stubborn' vegetation.

Each year the Office of Aerospace Technology recognizes the accomplishments that have most significantly contributed to the goals and objectives of the Enterprise. Ultimately they contribute to the mission and goals of the Agency. The *Turning Goals Into Reality* award is presented to each winning team at an annual ceremony. The 2002 award winners are described in this section.

After due consideration of the evaluation criteria and the merits of the 48 nominees, the Review and Validation Board recommends the following candidates for 2003 Turning Goals Into Reality (TGIR) awards in their respective goal and objective areas.

Administrator's Award

The Performance Data Analysis and Reporting System (PDARS) Team

PDARS is an innovative integration of data processing, information management, data visualization, and networking technologies. It rapidly processes large volumes of complex ATC data, supports a suite of visualization and analysis tools, all on a secure network that enables cross-facility collaboration. The PDARS network is a FAA mission-critical infrastructure complying with the many regulations implied by that designation. The PDARS system for processing complex data and reliably extracting information in meaningful displays enables users to quickly focus on the operationally significant problems.

Goal 1: Revolutionize Aviation

Aviation Safety Turbulence Prediction and Warning System (TPAWS) Team

Turbulence has been identified by the FAA, NTSB, and airline sources as a leading cause of in-flight injuries. The primary focus of TPAWS is to analyze and develop turbulence prediction and detection/warning systems and develop an aircraft-independent turbulence intensity index. The TPAWS flight research results represent a significant advance in the state of the art. Severe turbulence was detected within a 30-120 second window by unique turbulence prediction algorithms using radar sensor signals. Preliminary results indicate a 92 percent correlation factor over very wide ranges of turbulence intensities and aircraft types. The data collected also will be used to support NASA's development of weather event data sets that will be used to FAA-certify upgraded turbulence radar equipment.

Objective 1: Aviation Safety

Terrain Portrayal for Head-Down Displays Simulation and Flight Test Team

SVS displays present computer-generated three-dimensional imagery of the surrounding terrain to greatly enhance a pilot's situation awareness (SA) to mitigate accidents. An essential component of all SVS displays is an appropriate presentation of terrain to the pilot. Prior to the terrain portrayal for head-down displays (TP-HDD) combined experiments, the relationship between the realism of the terrain presentation and the resulting enhancements of pilot SA and performance was largely undefined. Composed of complementary simulation and flight test efforts, TP-HDD experiments evaluated critical terrain portrayal concepts that provided essential data to enable design trades that optimize SVS applications, and developed requirements and recommendations to support certification of SVS HDD.

Objective 2: Emissions Reduction

Turbine Airfoil System Deployment

This project aimed to develop a turbine airfoil system that provides a 200 to 300°F increase in blade surface temperature, allowing for higher engine efficiency and reduced CO_2 emissions. The effort developed a new, single-crystal blade superalloy and a new low-conductivity ceramic thermal barrier coating (TBC).

The resulting blade alloy demonstrated up to an 85°F increase in metal temperature capability over current production blade alloys. The TBC demonstrated a 200°F surface temperature capability increase for commercial applications, and in excess of 300°F for more aggressive, higher heat flux applications. System studies estimate that this new airfoil material system alone provides a fuel burn reduction equivalent to a four to six percent emissions reduction for a 300 passenger subsonic vehicle, contributing significantly (20 percent) to OAT's objective of reducing CO_2 emissions by 25 percent by the year 2007.

Objective 3: Noise Reduction

Fan Noise Reduction Team

This project demonstrated engine noise reduction through fan wake management. Fan rig tests showed that air injection through the blade trailing edge slots removed or reduced non-uniformities in the fan stream and led to substantial reductions (more than 10 dB) in fan interaction tone levels. These reductions translate into sizable benefits for current high bypass ratio turbofan engines resulting in 2 EPNdB reductions in fan component noise. For ultra-high bypass ratio turbofan engines, whose noise signatures are dominated by fan noise, potential trailing edge blowing benefits are even higher, approaching 4 EPNdB. Such reductions in fan noise level, when coupled with commensurate reductions in the level of noise from the airframe and other engine components, can achieve the OAT enterprise goal of reducing aircraft system noise by 10 EPNdB relative to 1997 technology.

Objective 4: Increase Capacity

The Advanced Terminal Area Approach Space Research Team

Researchers developed a terminal area approach spacing concept that has the potential to revolutionize aviation by increasing capacity at the nation's busiest airports. Applies the Advanced Terminal Area Approach Spacing (ATAAS) concept precisely delivers aircraft to the runway, increases runway throughput and system-wide efficiency. Today air traffic controllers use a radar-based position display to space aircraft on approach. This approach spacing tool, using the aircraft's position and planned flight path, provides speed commands directly to pilots, to achieve a precise runway arrival time. Due to the different speeds of aircraft, wind effects on approach, and the aircraft's deceleration this is a very complex problem to solve. This spacing tool uses Automatic Dependent Surveillance-Broadcast data link of aircraft state data and airport weather forecast data in its computations and uses simple pilot procedures and symbology to allow the pilots to easily follow the instructions. The objective of this tool is to allow accurate spacing of aircraft and the potential to reducing it, without compromising safety. The ATAAS tool has been evaluated in extensive simulations, with throughput benefits exceeding eight percent, very significant for the high demand airports. Other simulation evaluated pilot acceptability and workload followed by a flight validation in September 2002 at Chicago's O'Hare International Airport. This flight was conducted using NASA Langley's Airborne Research Integrated Experiments System Boeing 757, a Rockwell-Collins Sabreliner, and a Piper Chieftain. These aircraft flew over 30 approach scenarios and validated the ATAAS concept in an operational environment.

Objective 5: Mobility

SATS Airborne Internet Team

The limited capability and functionality of today's National Airspace System (NAS) Communications, Navigation and Surveillance (CNS) infrastructure does not support the SATS requirements, thereby preventing intercity door-to-door mobility from being enhanced, an OAT objective. NASA Glenn and its partners developed a new CNS system that delivers aviation information services in an internet-like manner to aircraft and ground facilities as interconnected nodes on a high-speed digital communications network. This revolutionary, integrated CNS concept is defined as the Airborne Internet and enables SATS Program CNS services. The resultant Internet Protocol (IP)-based Airborne Internet design and development allows intelligence redistribution from centralized to distributed nodes, thus enabling SATS Operating Capabilities of Higher Volume Operations and Single Pilot Workload, key factors to increasing U.S. mobility via SATS and, eventually, commercial aviation. The Airborne Internet's fundamental characteristics include: client server with confirmed delivery notification features; a robust high-capacity aviation information system for both air traffic control and safety advisories; integrated CNS; worldwide compatibility; seamless peer-to-peer connectivity; and high bandwidth and data rates.

Goal 2: Advance Space Transportation

COBRA Main Engine Project Team

Successfully accomplished challenging technical and programmatic goals that could lead to significant improvements in main engine propulsion safety, cost, and reliability. Accomplishments include design of a liquid-liquid pre-burner, and a milled channel-wall nozzle. The pre-burner provides a key enabling technology for next-generation engines by lowering temperatures and "smoothing" engine ignition. The nozzle was fabricated at 40-percent scale and structurally proof-tested at pressures up to four times higher than normal operation, validating a nozzle design which will improve safety, cost, and reliability, while reducing fabrication time from four years to one year. COBRA's innovative management controls and exemplary Government/contractor teamwork enabled several such technical accomplishments.

Objective 6: Mission Safety

Miniaturized Smart Leak Detection Sensor Team

Launch vehicle leak detection applications are important to avoid conditions that could harm personnel and damage vehicles, and improved leak detection techniques are necessary to meet the Advanced Space Transportation Mission Safety Objective of reducing the crew loss incidence by a factor of 40 within 10 years as well as reducing costs by a factor of 10. Existing leak detection systems limit capability in various NASA applications; there are often no space qualified systems to meet NASA needs. In response, a hydrogen leak detection system consisting of a microsystems based hydrogen sensor combined with supporting electronics has been developed that meets NASA and industry needs.

Objective 7: Mission Affordability

GRCop-84 Alloy Development Team

NASA Glenn invented a new, rugged, high-temperature alloy, GRCop-84, which far exceeds today's alloy capabilities and is developing it for future space vehicle use. Rocket engine combustion chamber liners are a major limiting factor for the space shuttle main engine (SSME) life and performance. Current NARloy-Z liner degradation results in performance loss plus high maintenance costs, while the long lead-time and high cost for producing liners limits their replacement potential and increases the cost of putting payload into orbit. The aerospace industry recognizes GRCop-84 as a potential replacement for the current alloy and has selected it as several new engines' baseline material. This alloy's commercial use will achieve an estimated 50 percent manufacturing cost reduction, 50 percent delivery time reduction, plus additional operational cost savings through an anticipated 2X-50X improvement in life (number of missions). Simultaneously with life improvement, GRCop-84's improved strength (2X) and temperature capability (+350°F) over today's alloys will provide rocket performance improvements.

Objective 8: Mission Reach

No Award Presented

Goal 3: Pioneering Technology Innovation

The Secure, Mobile, Wireless Network Technology Team

A NASA Glenn team successfully developed and demonstrated a revolutionary technology solution to seamlessly disseminate data securely over a high-integrity, wireless broadband network that will enable fundamentally new airplane system capabilities by enabling secure, seamless network connections from platforms in motion (i.e., aircraft and satellites) to existing terrestrial systems without the need for manual reconfiguration, thus addressing a primary technical barrier to providing an order of magnitude increase in aviation capacity and safety. Called "Mobile Router," the new technology autonomously connects and configures networks as they traverse from one operating theater to another. As a Mobile Router companion, the team also developed and demonstrated an entirely new, National Security Agency approvable, Type 2 encryption device, allowing secure communications across a diverse network topology. The new Mobile Router technology is already incorporated into open standards, making all demonstrated technologies commercially available and fully interoperable with existing terrestrial network devices.

Objective 9: Engineering Innovation

JavaPathFinder (JPF) Model Checking Team

Flight software costs in excess of $500 per line, dominated by the cost of testing. Advances in software development that could enable massive cost savings are not being used in flight software since current testing techniques cannot certify such system's correctness. A research team developed Java PathFinder, a revolutionary tool capable of automatically detecting errors in Java programs. Based on a technique called "model checking," JPF essentially allows an exhaustive analysis of a system to check whether certain behavioral properties hold. JPF demonstrated its ability to find subtle errors which escaped detection during traditional testing. The "model checking" research pioneered with JPF is being actively pursued by major companies and universities.

Objective 10: Technology Innovation

TEEK—A High-Temperature Polyimide Insulation

Under a NASA Space Act Agreement, NASA Langley Research Center and Unitika LTD developed TEEK, a low-density, flame-resistant polyimide foam that provides excellent thermal and acoustic insulation high-performance structural support. The synthesis of TEEK begins with a salt-like monomeric solution to yield a homogeneous polyimide precursor solid residuum. Utilizing state-of-the-art foaming techniques, the polyimide precursor solid residuum can be reacted into a variety of forms including but not limited to neat foam, syntactic foam, foam-filled honeycomb and microspheres. Over 25 different polyimide precursors have been processed into lightweight, high-strength polyimide foam for extreme temperature applications.

Goal 4: Commercialize Technology

Protective Coating for Ceramic Materials (PCCM)

The innovation PCCM is a coating material, which provides heat and fire protection to many substrates such as ceramic, wood and metal. The coating is capable of withstanding temperatures up to 3,000ºF and is environmentally friendly. The PCCM can easily be applied by spraying, brushing, or it can be incorporated as a constituent in wood or plastics. The coating can be used on any type of material, whether rigid, flexible or fabric. The coating was developed as an alternative to alleviate problems associated with the previous coating used for the flexible blanket insulations on the exterior of the Shuttle Orbiter. The initial primary application of the coating was to evaluate protection for Advanced Flexible Reusable Surface Insulation (AFRSI) blankets on the Shuttle Orbiter during reentry in the Earth's atmosphere and successfully flown on the Pegasus Glove Experiment as a coating for the gap fillers that resided between tiles and at the metal-to-tile interfaces. The coating has been licensed to Wessex, Inc. and through partnerships with numerous non-aerospace companies has been used on everything from NASCAR racecars through fabrication facilities to fire retardant materials to prevent the possible spread of fire in airline cargo containers.

The NASA Office of Aerospace Technology in partnership with the Education Enterprise sponsors education projects. Professionally designed learning activities and materials for students and teachers at all grade levels are developed annually.

These projects have been produced in close consultation with the educational community and are designed to support the national standards for mathematics, science, geography, and technology education. They are developed and implemented by the education offices at NASA field centers.

The following pages report key accomplishments the enterprise achieved toward realizing its goals for education. Expanded write-ups, images, and videos can be found on the supporting website at: *http://www.aerospace.nasa.gov*

Fun and Inspiring Education Websites

In 2002 the Aerospace Technology Enterprise developed and implemented a wide range of online educational programs designed to inspire interest in science, technology, engineering, and mathematics among young people of all ages.

- *Robin Whirlybird on Her Rotorcraft Adventures* (*http://rotored.arc.nasa.gov/*) is an interactive, multimedia story in which students in grades K–4 learn about the structure, function, and history of different types of rotorcraft.
- *Virtual Skies* (*http://virtualskies.arc.nasa.gov/*) helps students in grades 9–12 explore exciting worlds of aviation technology, air traffic management, and aviation research.
- *Reliving the Wright Way* (*http://wright.nasa.gov*) provides educators and students with a central location on the Wright Brothers and activities related to celebrating the 100th anniversary of their first powered flight.
- *NASAexplores* (*http://www.nasaexplores.com*) each week during the school term offers K–12 educators exciting lesson ideas in science, technology engineering and mathematics based on aerospace technology research.
- *Aeronautics Kids Page* (*http://www.ueet.nasa.gov/StudentSite/*) provides fun activities for young people interested in airplanes and jet engines.

Classroom Materials

The Aerospace Technology Enterprise has developed and shared with educators nationwide an impressive number of educational publications and multimedia products that promote learning by capturing the excitement of aerospace technology research.

- *Learning to Fly: The Wright Brothers' Adventure* offers a wealth of historical information about the Wright Brothers and provides students with detailed instructions for creating a model of the Wright Flyer.
- *Celebrating a Century of Flight* provides students with a colorful look at key aviation events in the past 100 years.
- *Exploring the Extreme* is a poster and educator guide set provides teachers a helpful collection of tools for teaching math and science in grades K–8.
- *NASA Aerospace Technology Education Resource Guide* is a CD–ROM product that contains a wide range of Aerospace Technology educational publications on one attractive multimedia package.
- *Earth to Orbit Engineering Design Challenge* allows students in grades 5–8 to learn fundamental engineering principles through exciting hands-on classroom activities.
- *Wright Brothers 2003 Game* gives young people a fascinating and fun glimpse into the world of the Wright Brothers. The game can be played via CD–ROM online at: *http://www.ueet.nasa.gov/StudentSite/*

- The Aerospace Technology Enterprise offers educators simple yet technically accurate simulation software to help science students understand the physics behind topics such as the shape of aircraft wings and operation of jet engines. The software can be downloaded at: *http://www.grc.nasa.gov/WWW/K-12/aerosim/*

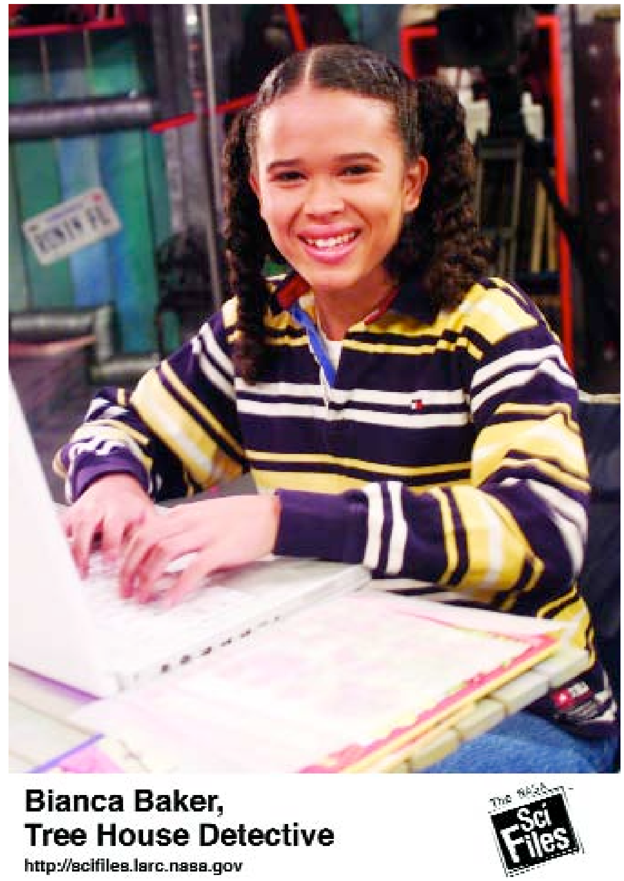
Distance Learning

Through a variety of distance learning programs, NASA seeks to enhance the teaching of math, science, geography, and technology in grades K–12. Feel free to explore the programs that are available for you as a student or educator.

NASA Science Files

NASA Science Files is a research and standards-based, Emmy-winning series of 60-minute instructional programs for students in grades 3–5.

Programs are designed to introduce students to NASA; integrate mathematics, science, and technology through the use of Problem-Based Learning, scientific inquiry, and the scientific method; and to motivate students to become critical thinkers and active problem solvers.



Bianca Baker, of Tree House Detective for NASA Science Files.

The series includes an instructional broadcast, a companion educator's guide, an interactive web site featuring a PBL activity, plus a wealth of instructional resources. The NASA Science Files airs nationally on Cable Access, ITV, and PBS-member stations. Presently, 194,000 educators, representing more than 4.3 million students in 50 states, have registered for the NASA Science Files. Program partners include Christopher Newport University, Hampton City Public Schools, Busch Gardens (Williamsburg, Virginia), Sea World (Tampa, Florida), the Society of Women Engineers, and the National Wildlife Federation.

Follow the exploits of the tree house detectives as they solve "real world" problems using mathematics, science, technology, and NASA with the help of community experts and resources, and members of the NASA Science Files Kids Club.

NASA Connect

NASA CONNECT is a research and standards-based, Emmy-winning series of mathematics-focused, instructional programs for students in grades 6–8. The series includes a 30-minute instructional broadcast, a companion lesson guide, and an interactive web-based application.

Hosts of NASA Connect: Jennifer Pulley and Dan Geroe.

Programs in the series establish a connection between the mathematics, science, and technology concepts taught in the classroom to those used everyday by NASA researchers. The lesson guide, containing a hands-on activity, and the web-based application reinforce and extend the objectives presented in the program. NASA CONNECT airs nationally on Cable Access, ITV, and PBS-member stations.

Presently, 260,000 educators, representing more than 8.9 million students in 50 states, have registered for NASA CONNECT. Program partners include the AIAA Foundation, Christopher Newport University, Epals, the National Council of Teachers of Mathematics, Riverdeep Learning Systems, and the National Wildlife Federation.

Destination Tomorrow

NASA's Destination Tomorrow is a series of 30-minute educational television programs that focus on NASA research, past, present, and future, and is designed for educators, parents, and adult (lifelong) learners.

Each program in this award-winning series follows a magazine style format with segments ranging in length from three to five minutes and six to eight minutes. The development of each program is based on the theory, principles, and educational research as they apply to how adults learn and apply knowledge.

Programs in the series are designed to (1) create and heighten adult interest in mathematics, science, technology, and NASA; (2) increase the scientific and information technology literacy of adults; (3) improve literacy of adults who do not use English as their primary language; and (4) to serve as a mechanism for parents and caregivers to become involved in the education of children and young adults.

An associated web site provides summaries of stories and links to related program material. Nearly 600 cable access and satellite TV stations air the series to an international audience of about 230 million viewers.

NASA Centers **for Aerospace Technology**

NASA Headquarters
Office of Aerospace Technology
Washington, DC 20546-001
Directory Information: 202-358-0000

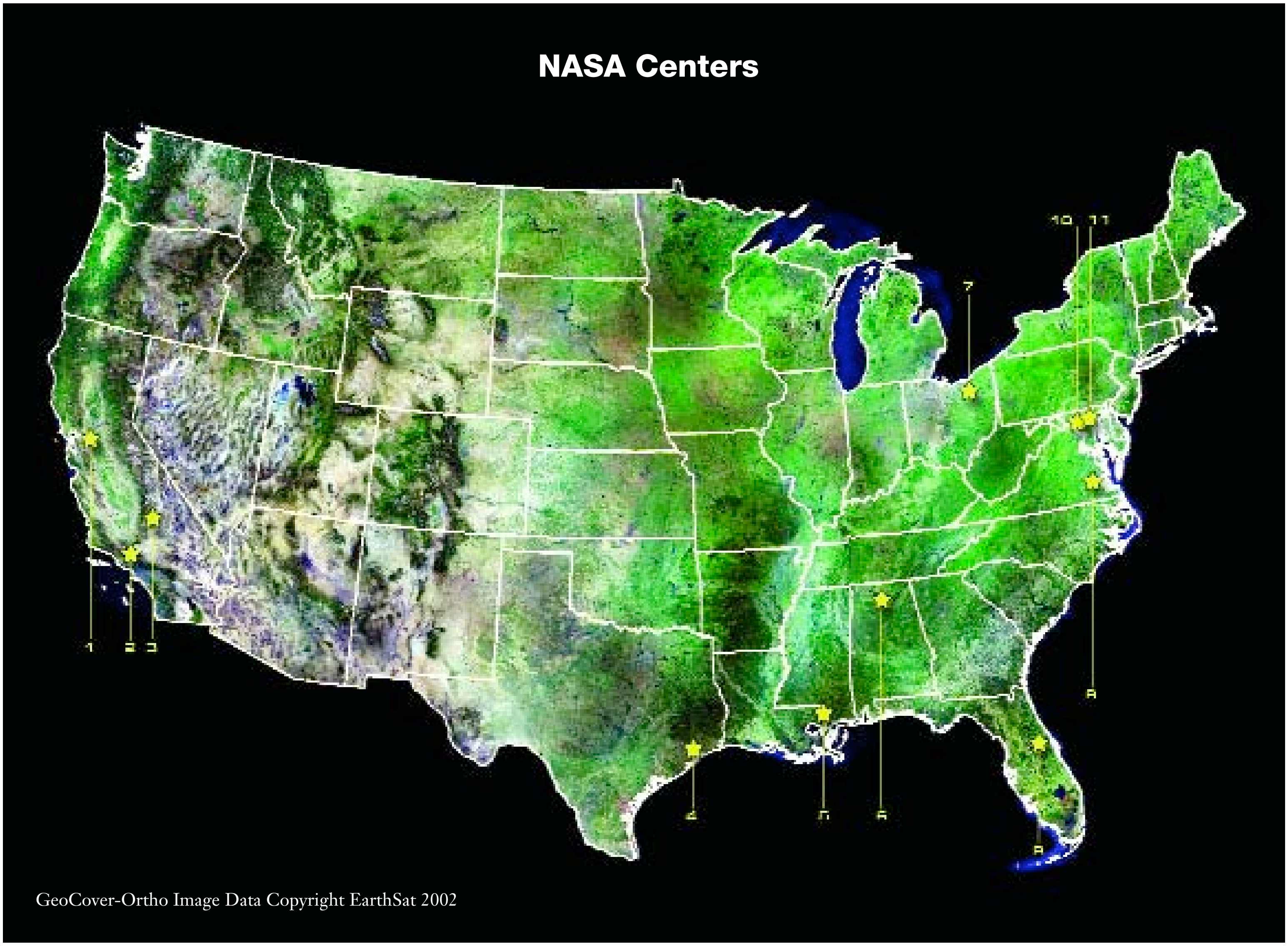
Ames Research Center
Moffett Field, CA 94035-1000
Directory Information: 650-604-5000

Dryden Flight Research Center
Edwards, CA 93523-0273
Directory Information: 661-276-3311

Glenn Research Center at Lewis Field
Cleveland, OH 44135-3191
Directory Information: 216-433-4000

Langley Research Center
Hampton, VA 23681-2199
Directory Information: 757-864-1000

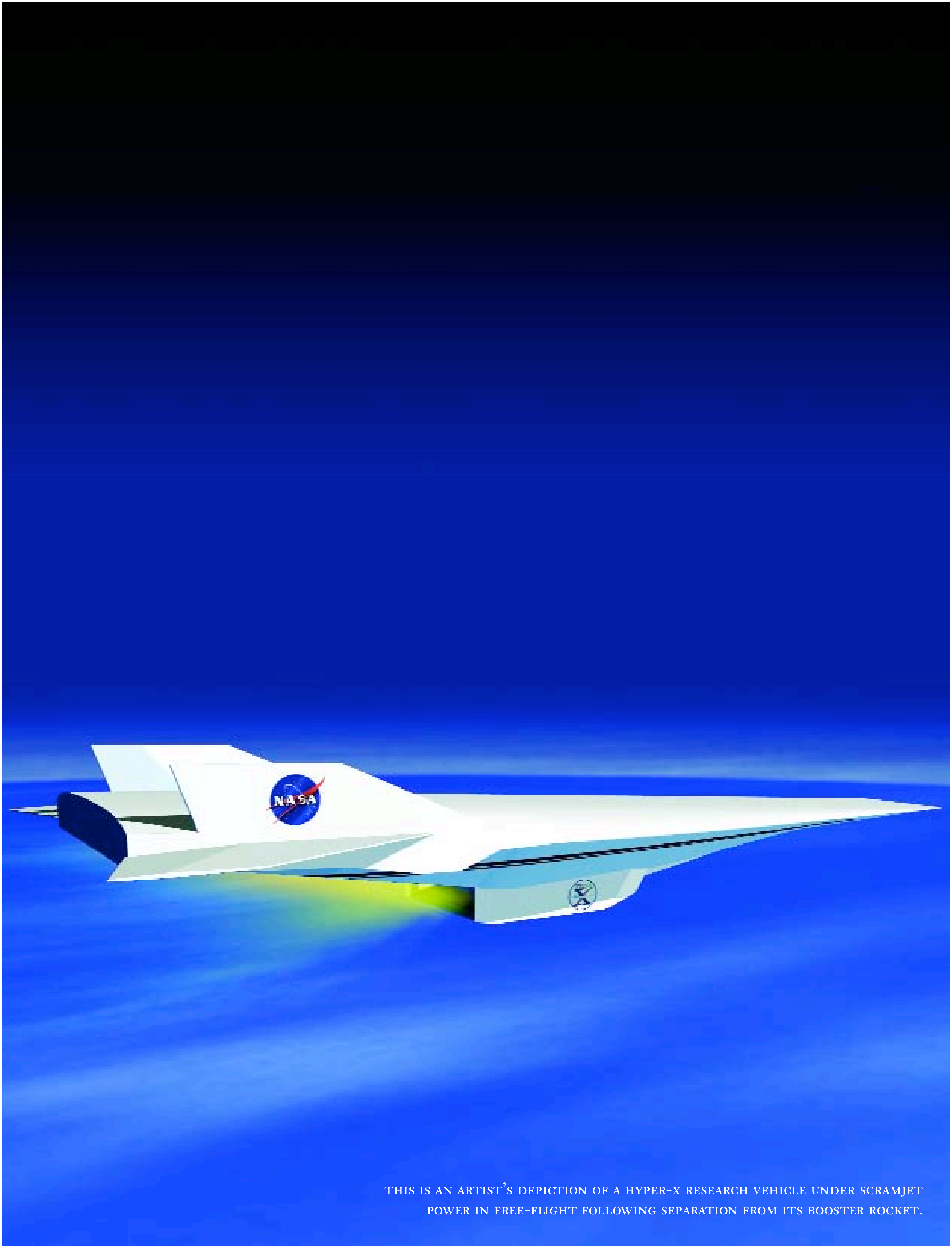
Marshall Space Flight Center
Marshall Space Flight Center, AL 35812-0001
Directory Information: 256-544-2121



NASA Center Locations	
1. Ames Research Center	**Mountain View, California**
2. Jet Propulsion Laboratory	Pasadena, California
3. Dryden Flight Research	**Edwards Air Force Base, California**
4. Johnson Space Center	Houston, Texas
5. Stennis Space Center	Stennis Space Center, Mississippi
6. Marshall Space Flight Center	**Huntsville, Alabama**
7. Glenn Research Center	**Cleveland, Ohio**
8. Kennedy Space Center	Kennedy Space Center, Florida
9. Langley Research Center	**Hampton, Virginia**
10. NASA HQ	Washington, DC
11. Goddard Space Flight Center	Greenbelt, Maryland

Centers in bold are the responsibility of the Aerospace Technology Enterprise.

These NASA Centers contain world-class research, design, and testing facilities that support our nation's aerospace research needs. These facilities help advance the state-of-the-art in aerospace technology. Tools and technologies ranging from small test rigs to advanced propulsion systems and wind tunnels support the testing of small-scale engineering models to full-size aircraft.



This is an artist's depiction of a Hyper-X research vehicle under scramjet power in free-flight following separation from its booster rocket.


CELEBRATING ONE HUNDRED YEARS OF POWERED FLIGHT, 1903--2003

Identification Key :
"Celebrating One Hundred Years of Powered Flight 1903-2003"
by Dr. Robert T. McCall
Master Study – December 2002 – Medium: oil on canvas
Dimensions: 24 inches by 72 inches
Numbering sequence: left to right, top to bottom.

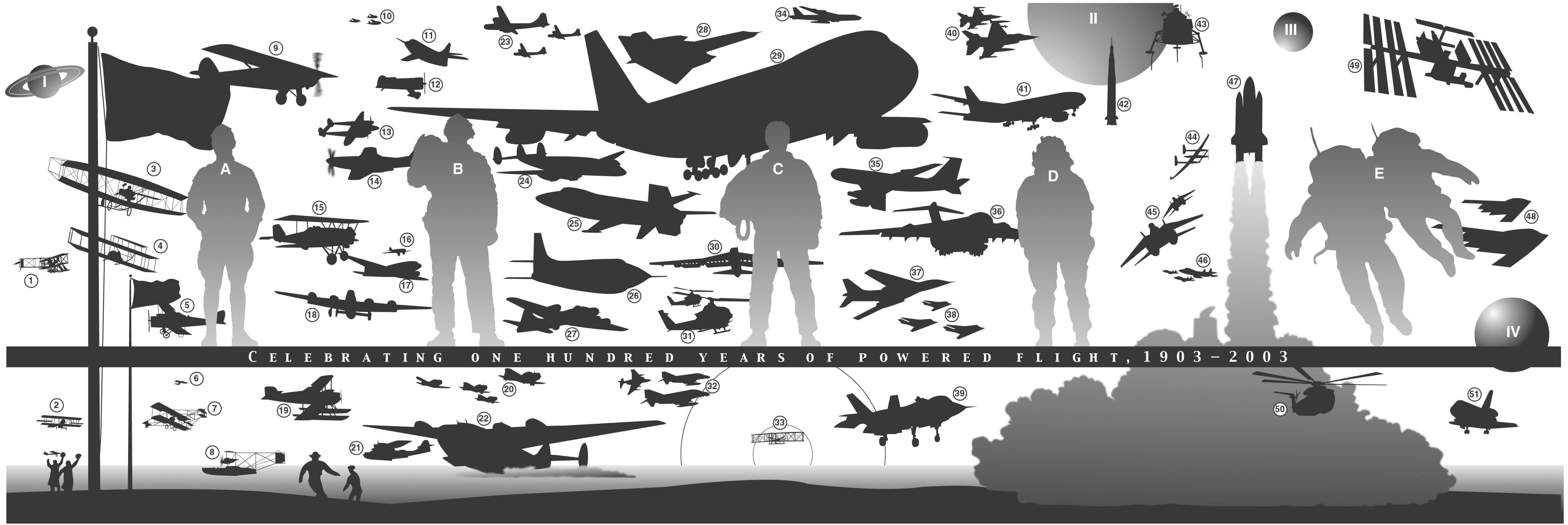
People

A. U.S. World War I Aviator
B. U.S. World War II Flier
C. NASA Research Pilot
D. NASA Shuttle Astronaut
E. Space Walkers

Planets

I. Saturn
II. Moon
III. Mars
IV. Jupiter

Aircraft and Spacecraft (Numbered 1-51)



1. Wright EX "Vin Fiz"
2. Curtiss Model D Headless Pusher
3. Curtiss June Bug
4. Wright 1909 Military Flyer
5. De Havilland DH-4
6. Bleriot XI
7. Curtiss 1911 Model D
8. Curtiss NC-4
9. Ryan NYP "Spirit of St. Louis"
10. Grumman TBF Avenger (formation)
11. Douglas D-558-2 Skyrocket
12. Granville (Gee Bee) R-1 Super Sportster
13. Lockheed P-38 Lightning
14. North American P-51D Mustang
15. Pitcairn PA-5 Mailwing
16. Northrop 4A Alpha
17. Douglas DC-3
18. Consolidated B-24 Liberator
19. Douglas World Cruiser (DWC)
20. Douglas SBD Dauntless (formation)
21. Consolidated PBY Catalina
22. Boeing Model 314 Clipper
23. Boeing B-29 Superfortress (formation)
24. Lockheed Constellation
25. North American X-15
26. Bell X-1 "Glamorous Glennis"
27. Boeing B-17 Flying Fortress
28. Lockheed SR-71A Blackbird
29. Boeing 747
30. Boeing B-52H Stratofortress
31. Bell AH-1 Cobra (formation)
32. McDonnell Douglas F-4D Phantom II (formation)
33. Wright 1903 Flyer
34. Boeing B-52B Stratofortress
35. Boeing 707
36. McDonnell Douglas C-17A Globemaster III
37. Rockwell B-1B Lancer
38. Lockheed F-117 Nighthawk "Stealth Fighter"
39. Lockheed Martin JSF X-35B
40. General Dynamics F-16 Fighting Falcon
41. Boeing 777
42. Apollo Spacecraft / Saturn V Launch Vehicle
43. Grumman Lunar Module (LM)
44. Rutan Model 76 Voyager
45. Grumman F-14 Tomcat (formation)
46. McDonnell Douglas F-15 Eagle (formation)
47. Rockwell Shuttle (Space Transportation System)
48. Northrop B-2 Spirit "Stealth Bomber"
49. International Space Station
50. Sikorsky CH-53 Sea Stallion
51. Rockwell Space Shuttle Orbiter

Source: The Smithsonian National Air and Space Museum, Directory of Airplanes, their Designers and Manufacturers by Dana Bell copyright 2002
ISBN 1-85367-490-7

National Aeronautics and
Space Administration

Office of Aerospace Technology
NASA Headquarters, Code R
Washington, DC 20546

http://www.aerospace.nasa.gov
NP-2003-06-306-HQ